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RECLASSIFICATION OF ANDEPTS OF THE STATE OF HAWAII IN THE PROPOSED ORDER ANDISOLS

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INTRODUCTION

Soil survey and classification have been utilized extensively for national development planning to expedite implementation of agro-industrial programs and increase food production projects. Cline (1949) wrote that, "natural or taxonomic classification performs the extremely important function of organizing, naming and defining the classes that are the basic units used (a) to identify the sample individuals that are the objects of research, (b) to organize the date of research for discovering relationships within the population, (c) to formulate generalizations about the population from these relationships and (d) to apply these generalizations to specific cases that have not been studied directly." These attributes of soil classification are best exemplified by _Soil Taxonomy_ (1975), a basic system of soil classification for making and interpreting soil survey, issued by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture (USDA). It provides a comprehensive classification system that groups soils with similar behavior and use as influenced by their physical and chemical properties (Uehara, 1978), hence, a useful tool in soil interpretation and prediction of land potential. Beinroth _et al_. (1974) commented that: "Soil Taxonomy is by far the most eleborate quantitative system of soil classification."

With all of the above qualities, it is highly likely that Soil Taxonomy will be adopted as a means of international communication. Owing to its newness, however, there are some limitations in Soil Taxonomy which need to be corrected.

Moormann(1979) asserted that soil taxa definitions for soils of the intertropical regions are not as well developed and require further attention. Hence, Beinroth (1979) commented that: "the need for changes will prevail in the forseeable future as more is learned about soil, particularly those of the tropics."

One of the areas that needs improvement in Soil Taxonomy is the classification of soils developed from volcanic ash. Some of the limitations in the classification of Andepts, as enumerated by Smith (1978)[1], are as follows:

1. The definition of Andepts excludes some volcanic ash soils, because the requirements apply only to soils having a bulk density of less than 0.85 g/cc and having an exchange complex dominated by amorphous materials throughout the upper 35 cm or to soils having more than 60 percent vitreous ash, etc. There are some volcanic ash soils that do not meet some of these requirements.

2. Base saturation by NH_4OAc is used as a differentia in the classification key. The values may not represent the actual base status of the soil because the clays are mostly amorphous and the CEC is largely pH-dependent.

3. Thixotropy as a differentia is very subjective because it is partly a function of the water content and partly a function of the stress applied. Thus characterization cannot be made uniformly.

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[1]Smith, G.D. 1978. Preliminary proposal for reclassification of Andepts and some Andic subgroups.

4. The soil moisture regime is used as a differentia for all other soils but not for Andepts. The interpretation for a given family, therefore, cannot be made without the use of a climatic phase.

5. The darkness of the epipedon is weighted heavily in the subgroup definition, but there seems to be little or no relation between color and carbon content, degree of weathering or any other property in the warm intertropical areas. Many volcaniclastic materials are black when deposited and become lighter in color only with weathering.

6. There is inadequate emphasis on the unique moisture retention properties of the Andepts. The irreversible effect of drying is used only to define the Hydrandepts and soils such as the Hydric Dystrandepts.

The above are some of the more compelling reasons prompting the reclassification of the suborder Andepts to the proposed soil order Andisols. Smith (1978) proposed a reclassification scheme, therefore, to better accommodate the soils developed from volcanic ash. Copies of this proposal were distributed by the International Committee on the Classification of Andisols (ICOMAND) for revision and amplification. ICOMAND is an international committee authorized by the SCS, USDA, to consider the proposal for providing the order of Andisols for those soils that are now Andepts (ICOMAND Circular No. 1).

The proposal, however, uses several parameters that were not used in previous classification of the Andepts. The test of the new proposal, therefore, is possible only if these parameters are available. With this in mind, some representative Andepts of Hawaii were selected and characterized to meet the following objectives:

1. To test the adequacy of the proposed scheme for reclassifying the Andepts.

2. To improve the proposed classification system for soil order Andisols.

3. To reclassify the Andepts of the State of Hawaii.

REVIEW OF LITERATURE

The proposed soil order is under international testing and it is in the process of being revised and modified before being adopted by the Soil Conservation Service of the United States Department of Agriculture. To obtain a better perspective of this activity, it is helpful to review briefly the proposal itself, and to see the additional contributions of the International Committee on the Classification of Andisols to the reclassification of soils derived from volcanic ash. It is also necessary to look at some of the basic rationales behind the criteria for reclassification. In order to appreciate the proposed changes, the explanations for such changes, as described in Circular No. 1 of ICOMAND (1979) are also included in this review.

Proposal for Classification of Order Andisols

The task of ICOMAND as authorized by the SCS, USDA to consider the reclassification of Andepts into the proposed order Andisols, consisted mainly of testing the preliminary proposal prepared by Smith (1978). ICOMAND operates by correspondence between the committee and its members from all regions of the world having volcanic ash soils.

The definitions used in the reclassification of soils developed from volcanic ash transfers requirements of Andepts and Andaquepts from Inceptisols to Andisols.

The proposed order Andisols is provided with six suborders and 22 subgroups. The list of suborders, great groups and subgroups are shown in the Appendix.

Definition of Andisols

The definition of Andisols (Smith's proposal, 1978, as attached to ICOMAND Circular No. 1) is as follows:

Andisols are mineral soils that do not have an aridic moisture regime or an argillic, natric, spodic, or oxic horizon unless it is a buried horizon, but have one or more of a histic, mollic, or umbric epipedon, or a cambic horizon, a placic horizon, or a duripan; or, the upper 18 cm, after mixing, have a color value, moist of 3 or less and have three percent or more organic carbon in the fine earth; and, in addition, have one or more of the following combinations of characteristics:

1. Have to a depth of 35 cm or more, or to a lithic or paralithic contact that is shallower than 35 cm but deeper than 18 cm, a bulk density of the fine earth fraction of less than 0.85 g/cc (at 1/3-bar water retention of undried samples) and the exchange complex is dominated by amorphous materials.
2. Have, in the major part of the soil between a depth of 25 cm and 1 m or a duripan, a placic horizon, or a lithic or paralithic contact that is deeper than 35 cm but shallower than 1 m, a bulk density of the fine earth fraction of less than 0.85 g/cc (at 1/3-bar water retention of undried samples) and the exchange complex is dominated by amorphous materials.
3. Have 60% or more, by weight, of noncalcareous vitric volcanic ash, pumice or pumice-like fragments, cinders, lapilli, or other vitric volcaniclastic materials either to a depth of 35 cm or more, or in the major part of the soil between 25 cm and 1 m or a lithic or

paralithic contact that is shallower than 1 m, and the pH in the major part of these horizons of 1 g of fine earth in 50 ml of 1 N NaF is 9.2 or more after 2 minutes.

4. Have a weighted average (by thickness of subhorizons) in the major part of the soil between a depth of 25 cm and 1 m or a duripan or paralithic or lithic contact shallower than 1 m, a water retention of undried fine earth at 15-bars pressure of 40% or more; and either a ratio of 15-bar water percentage (undried) to the meq exchangeable bases is 1.5 or less, or the pH of 1 g of fine earth in 50 ml of 1 N NaF is 9.4 or more after two minutes, or both.

Item 1 is used to classify the shallower volcanic ash soils, while item 2 accommodates deeper soils which may have low amorphous material in the surface horizons. Item 3 clarifies the classification of soils formed in ash but belonging to the other soil orders. Smith (1978) in his proposal explained that: "if a soil with a bulk density greater than 0.85 g/cc is classified as Andisols because it has formed in ash, and glass is thought to be present, it must react to NaF." Item 4 defines additional properties of the volcanic ash soils. This is intended for the Eutrandepts of Hawaii that meet the definition of Andisols except for the requirement of pH in NaF because the test may be meaningless due to its calcareous lower horizons. Item 4 also requires a low ratio of 15-bar water percentage to exchangeable bases to suit the relatively high exchangeable bases and low 15-bar water retention of undried material of the Eutrandepts. This provision was questioned because of its application to soils such as the Hydraquents (Grossman, 1978, ICOMAND Circular No. 1). Accordingly, Smith (1979) amended Item 4 by adding the words, "an ustic moisture regime and the bulk density of the fine earth fraction of less than 0.9," after the words, "a water retention of undried fine earth at 15-bars pressure of 40% or more."

For organic carbon, a diagnostic limit of 3 percent of more in the fine earth was intended to eliminate the influence of color in the basaltic or andesitic ash, cinders, and lapilli, all of which are nearly black and meeting the requirements for the color value, moist, of 3 or less in the upper 18 cm of the soil.

Issues, Suggestions, and Proposed Revisions

The use of andic epipedon was suggested by Alvarado and Buol (1980, ICOMAND Circular No. 2). The proposed andic epipedon is defined as "the umbric epipedon but with a bulk density lower than 0.85 g/cc (by the core technique), the exchange complex dominated by amorphous materials and developed from 60% or more (by weight) non-calcareous materials, vitric volcanic ash, pumice or pumice-like fragments, cinders, lapilli or other vitric volcaniclastic materials either to a depth of 35 cm or more, or in the major part of the soil between 25 cm and 1 m or a lithic or paralithic contact that is shallower than 1 m, and the pH in the major part of these horizons of 1 g of fine earth in 50 ml of 1 N NaF is 9.2 or more after two minutes."

By this definition, Andisols will be defined as what they are instead of the negative definition as proposed.

A common but important property of Andisols is the low bulk density, which by definition is less than 0.85 g/cc. There are, however, some criticisms and suggestions about this parameter.

The substitution of bulk density by void ratio was recommended. The rationale is that void ratio is used more in soil mechanics and that it is pertinent not only to plant growth but also in non-agricultural uses (Grossman, 1978 ICOMAND Circular No. 1). The substitution of bulk density by void ratio, however, was opposed until it could be shown that void ratio has more predictive values for plant growth than bulk density, (Thomas, 1979, ICOMAND Circular No. 1). Thomas asserted that the calculation of void ratio requires the measurement of particle density which would then entail additional work, thus, the extra effort should be justified.

Exchange Complex Dominated by Amorphous Material (ECDAM)[2]

The required conditions of ECDAM as proposed by Blakemore (1978) are as follows:

1. The bulk density of the fine earth fraction should be <0.85 g per cubic centimeter at 1/3-bar tension, with undried samples.
2. If there is enough clay to have a 15-bar water content of 15% or more in air dried samples, the pH of a suspension of 1 g soil in 50 ml 1 M NaF is >9.4 after 2 minutes.
3. The Phosphate Retention value should be >90%.
4. The Variable Charge should be >0.7 of the CEC at pH 8.2 (using $BaCl_2$).

Justification of such ECDAM requirements were briefly discussed (Blakemore, 1978, as attached to Smith's proposal).

Bulk Density - Generally, bulk density is being used as index to

[2]Blakemore, L.C. 1978. Exchange Complex Dominated by Amorphous Material, as attached to Smith's proposal.

the porosity and structural condition of the soils. In relation to the suggested conditions of ECDAM, Blakemore commented that: "It will, in the main, confine the soils involved to amorphous and organic soils."

Phosphate Retention - The use of anion exchange property of soils have been commonly ignored as a criterion for soil characterization. It is known, however, that soils containing high amounts of amorphous material have a high anion exchange capacity, emphasizing the influence of the exchange complex of the clay.

In his proposed definition for ECDAM, Blakemore described the significance of phosphate retention as a reliable means of differentiating amorphous material from organic material, because P-retention value of organic materials is relatively lower then those of amorphous materials. In other words, organic soils could be differentiated from soils high in amorphous materials by the lower P-retention value of the former, even though both soils have a ratio of variable charge greater than 0.7 of the total charge.

Variable Charge - A major portion of the total charge of soils high in amorphous or organic materials is variable with pH and the proportion of variable charge in soils high in amorphous or organic materials is greater than 70 percent of the total charge (Blakemore, 1978).

Another suggestion submitted to ICOMAND about the variable charge ratio was that 0.7 is too low to be useful and that

$$\frac{(\text{Exch. Acidity at pH 8.2 - Al by KCl}}{\text{CEC at pH 8.2}} > 0.8$$

would be a more appropriate critical level (ICOMAND Circular No. 1, page 8).

A different index for the variable charge suggested by Eswaran (1979) was:

$$\frac{\text{CEC at pH 8.2 - (Bases + Al)}}{\text{2.5 x 15-bar water (air-dry soil basis)}} \times 100 > 50$$

Eswaran's proposal, however, was criticized because organic matter can increase the index above 50 in soils which are not dominated by amorphous constituent. Nevertheless, a proposal was made to preclude topsoils in order to avoid the effect of organic matter (ICOMAND Circular No. 1).

pH in NaF - The proposed pH requirement of a suspension of 1 g of soil in 50 ml of 1 M NaF is >9.4 after 2 minutes.

The pH in 1 M NaF at 1:50 ratio has been used and recommended by Fieldes and Perrott (1966) as a suitable laboratory test for the presence of allophanic material.

Amorphic Mineralogy

In 1979, Smith suggested some revisions to his original proposal. One was the use of the amorphic mineralogy class when particle size and combinations of mineralogy are not used. He explained that there are some soils of other orders that are excluded from Andisols and from andic subgroups simply because they do not meet the bulk density requirements. These soils, however, contain enough amorphous material to have a pH of 11 or more in NaF after 2 minutes and satisfy the P-retention values required in Andisols. Hence, they are grouped with other soils that lack such properties. This prompted Smith (1979) to propose the addition of an amorphic class to the mineralogy classes key for Soil Taxonomy, page 387, which he defined as, "enough amorphous materials that release OH^- to F^- to have a pH of 9.4 or more if, after any carbonate is removed, 1 g of soil is suspended in 50 ml of 1 M NaF for 2 minutes, and have P-retention of 80% or more. The determinant size fraction would be the whole soil particles less than 2 mm in diameter."

The above suggestion was favored because an amorphic mineralogy class could be a distinctive soil property associated with volcanic ash (Leamy, 1978, ICOMAND Circular No. 1). In this regard, however, there have been conflicting opinions on the definition of amorphous materials, because of the various modern techniques for determining a soil's mineralogy. ICOMAND members from Japan mentioned that amorphous materials are composed of allophane, imogolite, allophane-like materials, R_2O_3 materials combining humus, etc. (ICOMAND Circular No. 1). This is in agreement with the impression that amorphous material contains high amounts of imogolite which shows relatively low P-retention (<90%) (Smith, 1979, ICOMANDCircular No. 1). The consensus then was that the amorphous material should include imogolite as well as allophane.

The term imogolite was first used by Yoshinaga and Aomine (1962) to mean the component of soils derived from glassy volcanic ash found in the Imogo soil in Japan. This is the same material that Henmi and Wada (1976) characterized to be coexisting with allophane. Swindale (1965) was perhaps referring to the same material when he observed that accessory surface amorphous colloids also exhibited some properties not contained in the definition of allophane. Sherman *et al.* (1964) broadened the definition of amorphous materials to include allophane (hydrous colloidal aluminosilicate); hydrous oxides of Al, Fe, Mn, Si, and Ti; hydroxides of Fe and Al; and gels of Al, Fe, Si, and Ti.

Van Olphen (1971) reported a proposed tentative definition that: "allophanes are members of a series of naturally occurring minerals which are hydrous aluminum silicates of widely varying chemical composition, characterized by short range order, by the presence of Si-O-Al bonds, and by differential thermal analysis curve displaying a low temperature endotherm and a high temperature exotherm with no intermediate endotherm."

Later, through the use of the latest analytical equipment, it was again proposed that the term "amorphous material" should not include imogolite and allophane. The reason was that although they possess many of the properties of amorphous material, imogolite and allophane were observed to have definite and unique structures and, therefore, could not be considered to be amorphous. Those that have been previously regarded as amorphous appeared to be either weakly crystalline or purely amorphous by x-ray diffraction analysis. However, when examined by electron diffraction, these materials showed a definite morphology and a short range of crystallographic order (R.C. Jones, personal communication). Imogolite displays a definite fibrous, or thread-like morphology and allophane submicrometer size spherules that are hallow or polyhedrons (Henmi and Wada, 1976). These more recent findings perhaps led to later suggestions on the use of the terms "disordered material" or "active Fe and Al," instead of amorphous material (Parfitt, 1979, ICOMAND Circular No. 1).

So far no consensus have been made on the definition of amorphous material. The main reason perhaps is the fact that better and higher resolution electron microscopes are being used to reveal higher degree of orderliness of structure.

To avoid the problem of using the term "amorphous material," G. Uehara (personal communication) and Van Olphen (1980, ICOMAND Circular No. 2) suggested the use of the term "short range order material." From here on, the term "short range order material" (SROM) will be used in the succeeding discussions instead of "amorphous materials." Also included in the definition of short range order material is the mineral imogolite which is in fact an "intermediate range" material in that it produces distinct but broad x-ray diffraction maxima.

A better understanding of the short range order materials may be achieved by reviewing briefly some earlier investigations about their constituents.

It is of course known that volcanic ash is the soil forming material that weathers relatively fast into volcanic ash soil. The non-crystalline glass phase of volcanic ash is the one that is most likely to weather to allophane and imogolite (Voss, 1970). Allophane was first described by Ross and Kerr (1934) to include any short range order material in the clay mineral. With more concern on the chemical nature of allophane, it was later defined with definite SiO_2/Al_2O_3 mole ratio and surface area to separate it from other distinct non-crystalline material (Swindale, 1965; and Yoshinaga, 1966). Miyauchi and Aomine (1966) described imogolite as one having a SiO_2/Al_2O_3 mole ratio of near 1. Similarly, Henmi and Wada (1976) drew inferences that: "first, the higher the imogolite content, the lower the SiO_2/Al_2O_3 ratio of the fine clay; second, allophane has a mole ratio ranging from at least

1 to 2, while imogolite has a ratio close to 1." This led Voss (1970) to conclude that Akaka and Hilo soils of the island of Hawaii have little or no allophane, if allophane is defined to have a SiO_2/Al_2O_3 mole ratio of between 1 and 2. He indicated that the non-crystalline allophane-like material was a hydrated alumina, which is roughly analogous to imogolite, a percursor of allophane described by Yoshinaga (1968) and Kanno _et al_. (1968). Hudnall confirmed that the SiO_2/Al_2O_3 molar ratios of the volcanic ash soils of Hawaii were lower than those necessary for allophane formation. This also conformed with the molar ratio of imogolite obtained earlier by Wada and Yoshinaga (1969). In a more specific manner, Wada and Wada (1976) showed that non-crystalline hydrous oxides are major constituents and that allophane is a minor constituent in the clay fraction of Hydrandepts.

The above findings show in common that allophane is not the dominant material in Hawaiian Hydrandepts.

Proposals for Reclassification in the Lower Categories

Suborder Category

The key to suborders is in Appendix A. The proposed suborder are more or less parallel with the suborders of several other orders (ICOMAND Circular No. 1). The suborder Tropands, however, was added to emphasize the color of the Andepts. It has been explained in that Circular that the color as a differentia for Andepts in warm, humid, intertropical areas is poorly related to carbon or CEC and that a different differentia is imperative. This is demonstrated by the Andepts of Hawaii which have color value, moist, of 3 or less, because the dark color is due to iron rather than carbon (G. Uehara and G. Gillman, in press)[3].

Other proposals were the creation of new suborder Orthands to include shallow mineral soils developed from lava flows and the elimination of Tropands to avoid redundant use of the soil temperature regime in the suborder level and at the family level (Alvarado, 1980, ICOMAND Circular No. 2).

Great Group Category

Appendix A also shows the key to great groups and the explanations of the proposed great groups which are briefly summarized in ICOMAND Circular No. 1 (1978).

The Xerands and Ustands which are the soils that are dry seasonally were both provided with the Duric great group.

The proposal provided Hydric great groups for the freely drained soils that rarely or never become drier than field capacity. It has a limit of 100 percent 15-bar water on undried samples which is the same as that required for the hydrous combinations of particle size and mineralogy. A feeling of uncertainty of the existence of Hydrudands was mentioned although most Hydrandepts easily exceed the limit of 100 percent 15-bar water.

Placic great groups are provided in Borands, Udands, and Tropands; vitric great groups in all suborders; and melanic great groups are proposed tentatively in Borands and Udands. The significance of the

[3]Goro Uehara and Gavin Gillman. The mineralogy, chemistry and physics of tropical soils with variable charge clays. In press.

black color is not clear (Smith, 1979, ICOMAND Circular No. 1), but black soils have been distinguished from other Andisols.

The proposed great groups of Orthands are Bororthands, Vitrorthands, Udorthands, Ustorthands, and Xerorthands (Alvarado, 1980, ICOMAND Circular No. 1). Similarly, Alvarado suggested the addition of great groups Tropudands and Tropustands for suborders Udands and Ustands respectively in accordance with his suggestion to eliminate Tropands in the suborder category.

Subgroups Category

The list of proposed subgroups and their definitions is in Appendix A. The proposed subgroups were felt necessary for the various great groups that have been proposed. Anthraquic subgroup was also suggested and defined as: "Perudic man-induced water saturation and reduction of the soil to a depth of 40 cm, without a corresponding water saturation in the horizon below" (Moorman and Breemen, 1978, ICOMAND Circular No. 2).

Family Differentiae

Appendix B of this thesis shows the new proposal for the definition of classes of combinations of particle-size and mineralogy.

The definition of classes of combinations of particle-size and mineralogy in Soil Taxonomy are difficult to use in the field. The proposal attempts to eliminate these difficulties by making the definitions more quantitative. For instance, thixotropy is determined as a function of the stress applied between the fingers and the moisture content of the sample. The proposal is to substitute thixotropic with the term hydrous. Hydrous is defined to have a water retention of

15-bars of 100 percent or more on undried samples of the fine earth. Ashy is defined as having less than 30 percent 15-bar water retention on undried, and less than 12 percent on air-dried samples, while medial is defined as having 12 percent or more on previously dried samples or between 30 to 100 percent of undried samples. The percentage loss of water on drying is assumed to be a function of the environment and the 15-bar water of the air dry sample is a function of the amount of amorphous clay (Smith, 1978).

MATERIALS AND METHODS

Materials

Soils

The soils selected for this reclassification study were:

1. Hilo silty clay loam (Typic Hydrandepts, thixotropic, isohyperthermic).
2. Akaka silty clay loam (Typic Hydrandepts, thixotropic isomesic).
3. Kukaiau silt loam (Hydric Dystrandepts, thixotropic, isothermic).
4. Waimea very fine sandy loam (Typic Eutrandepts, medial, isothermic).
5. Waimea silt loam (Typic Eutrandepts, medial, isothermic).
6. Waimea loam (Typic Eutrandepts, medial, isomesic variant).

These soils were selected because they have been extensively studied in Hawaii and because much information is avilable for further study. Besides, they belong to the great groups of Andepts (Dystrandepts, Eutrandepts, and Hydrandepts) having the largest number of soil series, 24, 17, and 16 respectively. The Hilo soil, for example, is one of the important soils of the northeastern part of the island of Hawaii devoted to sugarcane for the past one hundred years (Fig. 1). The Kukaiau series has also been used extensively for sugarcane. In addition, the particular soil family, of which the Kukaiau series is a member, is used in the Benchmark Soils Project (BSP) to test the hypothesis of agrotechnology transfer (BSP, 1977). The Waimea soil

Fig. 1. Landscape of an Acric Hydrotropands, hydrous, isohyperthermic.

represents the slightly weathered Andepts of the dry, cool, subhumid areas devoted to the production of vegetable crops and considered among the best pasturelands of the Hawaiian Islands (Cline et al. 1955). Fig. 2 shows the landscape of Waimea soil. The Waimea silt loam and Waimea loam were not originally included in this study. However, they were considered later to verify the lower P-retention values obtained earlier in the Waimea very fine sandy loam when compared with the other Andepts.

Sources of Information used for Reclassification

The sources of available data used in the reclassification of Andepts to the proposed order Andisols are:

1. Soil Survey Laboratory Data and descriptions for some soils of Hawaii, Soil Survey Investigation Report No. 29, (SCS, USDA, 1976).
2. Classification of the soil series of the State of Hawaii in Different System (Beinroth et al. 1974).
3. Circular Nos. 1, 2, and 3 (ICOMAND, 1979, 1980a, 1980b).
4. Laboratory Data and Descriptions of Soils of the Benchmark Soils Project (Ikawa, 1979).
5. Hawaii Soil Data Bank.

Other important data necessary for classification were determined in the laboratory as described in the succeeding sections.

Methods

The soil parameters required in the classification proposal that were not available from earlier investigations were: (a) bulk densities of clod samples at 1/3-bar water pressure ($Db_{1/3}$) and at field state

Fig. 2. Landscape of a Typic Haplustands, medial, isothermic.

(Db_f); (b) 15-bar water content of dried and undried sieved samples; (c) pH in NaF, and (d) P-retention.

Soil sampling - Although the samples of the different soils were available in the laboratory, fresh samples were collected in the field to perform the different laboratory analyses on samples which had not dried during storage. The exceptions were two of the Waimea soils (Waimea silt loam and Waimea loam) which were analyzed in the later stage of this investigation. Former profile sites were resampled so that the existing data could also be used.

The fresh samples were collected from a newly exposed profile face and placed in double plastic bags to minimize drying. Natural clods ranging in diameter from 4 to 6 cm were collected from the different horizons for subsequent bulk density determinations. On arrival at the laboratory, the samples were placed in another double plastic bag and stored on shelves to preserve the clods and retain field moisture.

There is evidence that dehydration of soil samples can alter some of the chemical, physical and mineralogical properties of soils derived from volcanic ash (Lim, 1976; and Kanehiro and Sherman, 1956). For this reason, only the required amount of sample needed for any given analysis was removed from the bags.

Measurement of soil pH - The rapid field and laboratory test by Fieldes and Perrott (1966) for allophane with acqueous NaF solution was used. The pH_{NaF} values were measured with a Beckman digital pH meter as outlined in method 8C1d of the Soil Survey Investigation Report No. 1 (Soil Survey Staff, 1972). Because air drying may alter the samples and consequently the data, the following tests were also made in addition to the prescribed procedure:

1. pH_{NaF} at oven dry, air dry and field moist conditions;
2. The technique of stirring the suspension; and
3. pH_{NaF} at undried and oven dry weight equivalents.

To get the ΔpH, the pH_{H_2O} and pH_{KCl} were determined by using methods 8Cla and 8Clc, respectively, of the SSIR No. 1 (Soil Survey Staff, 1972).

Determination of Phosphate Retention - P-retention was determined by the method recommended by Blakemore (1978), a method widely used in New Zealand in the characterization of Andepts for their anion exchange ability.

P-retention solution was prepared by dissolving 8.809 potassium dihydrogen phosphate (KH_2PO_4), A.R. and 32.8 g anhydrous sodium acetate (CH_3COONa), A.R., in distilled water, and added 23 ml glacial acetic acid, A.R. This mixture was diluted to 2 liters. The pH of this solution was expected to be between 4.55 and 4.65.

The Nitric Vanadomolybdate Acid reagent was prepared by adding first the vanadate solution and then molybdate solution to 1 liter dilute HNO_3.

The Vanadate solution was prepared by dissolving 0.8 g ammonium vanadate, A.R. in 500 ml boiling distilled water, cooled the solution and added 6 ml concentrated HNO_3, A.R. This solution was diluted to 1000 ml distilled water.

The molybdate solution was prepared by dissolving 16 g ammonium molybdate in distilled water at 50 degrees centigrade, cooled and diluted to 1 liter.

Dilute HNO_3 was prepared by diluting 100 ml HNO_3, A.R. to 1 liter. To a 5 g air dry soil sample (2 mm), 25 ml P-retention solution was added, shaked for 24 hours, and centrifuged at 2,000 rpm for 15 minutes.

Working solutions were prepared by pipetting 0, 10, 20, 30, 40, and 50 ml aliquots of P-retention solution (1 mg P/ml) into 50 ml flasks and made to volume with distilled water. These standard solutions contained 0, 0.2, 0.4, 0.6, 0.8, and 1.0 mg P/ml and corresponded to 100, 80, 60, 40, 20 and 0 percent retention, respectively. An aliquot of 1 ml from the sample solutions and from the working standards were dispensed into 30 ml tubes with 19 ml of nitric vanadomolybdate acid reagent. Color was allowed to develop for 30 minutes then absorbance was measured at 466 nm with a Spectronic 20, Bausch and Lomb colorimeter.

Determination of Bulk Density

1. Field State (Db_f) - Natural clods ranging in diameter from 4 to 6 cm were used to determine the bulk density in the field-moist state.

At the start of the laboratory work, the paraffin method was used because saran was not available. Inasmuch as saran was eventually used, an attempt was made to compare the bulk density values obtained by the two methods.

The methods 4A2 and 4A1a as outlined in SSIR No. 1 (Soil Survey Staff, 1976) using paraffin and saran, respectively were employed to obtain the Db_f values.

2. 1/3-Bar (Modified Paraffin Method) - As in the determination of Db_f, the paraffin method was used before saran was made available.

Because both methods were eventually used, it was again possible to compare the bulk density values obtained by the paraffin as well as the saran method. Method 4Ale for 1/3-bar desorption, as outlined in SSIR No. 1 (Soil Survey Staff, 1972) was used with some minor modifications.

The 15-bar ceramic plate extractor, Model No. 1500 and a 15-bar ceramic plate cell, Cat. No. 159 were used for 1/3-bar desorption. (All Models and Cat. Nos. mentioned are specifications of the Soil Moisture Equipment Corporation, U.S.A.).

Two flat surfaces were made on the clod samples with a sharp knife, and then the clod was tied with string. This was done to provide easier handling of the clods and avoid crushing the clods when the ceramic plate cells were placed one on top of the other inside the extractor.

Sieved soil samples were first placed at 3/4-full in the retainer rings, and then covered with small squares of industrial tissues (Kim-wipes). The clods were then placed on top of the sieved samples of the same soil and allowed to soak with water by capillary action. After saturating for 48 hours, the samples were placed inside the pressure plate extractor and 1/3-bar pressure was applied until no more water was extracted. The clods were quickly weighed in air ($Wc_{1/3}$) and immediately coated with paraffin and then weighed again (Ww). Then coated clods were weighed while immersed in water (Wo). Care was taken not to lose any soil material in the process. The paraffin coating was peeled off and the clod samples were placed in moisture cans and dried in an oven at 110^{o}C. The 1/3-bar water content of the sieved samples placed in the same retainer rings with the clods was determined in the same manner to serve as a check for the clod moisture. The weights of clods ($Wc_{1/3}$) and sieved samples ($Ws_{1/3}$) at 1/3-bar water content and the oven-dry weights of clod (W_{ODC}) and sieved samples (W_{ODS}) were determined separately. The weight of water (W_{H_2O}) in the clod was estimated as follows:

$$W_{H_2O} = Wc_{1/3} - W_{ODC}$$

Moisture factor (MF) was calculated in the following manner:

$$MF = 1 + \frac{W_{H_2O}}{W_{ODC}}$$

The steps in calculating the bulk density at 1/3-bar water content ($Db_{1/3}$) were as follows:

a. Wt. of wax (Wwax) = ($Wtc_{1/3}$ + wax in air) - ($Wtc_{1/3}$)

b. Volume of wax (Vwax) = $\frac{Wwax}{Pwax}$, where Pwax = 0.9

c. Volume of clod (Vc) = $\{\frac{Ww-Wo}{Sp\ gr\ H_2O}\}$ - Vwax

d. Wt of clod at 1/3-bar ($Wc_{1/3}$) = $Wc_{1/3}$

e. Bulk density at 1/3-bar ($Db_{1/3}$) = $\frac{Wc_{1/3}}{Vc}$

3. Bulk Density at 1/3-Bar (Saran Method) - The Saran coated clod method was used later to determine the bulk density at 1/3-bar. The $Db_{1/3}$ was calculated as outlined in method 4A1 of the SSIR Report No. 1 (SCS, USDA, 1972).

Measurement of Water Retention

The 15-bar water retention values were obtained separately for the dried and undried samples by using methods 4B2 and 4B2a, respectively, described in SSIR No. 1 (Soil Survey Staff, 1972).

A 15-bar ceramic plate extractor utilizing the 15-bar ceramic plate cells, Cat. No. 1590, was used to extract the water. For the undried samples, about 10 g of soil that had been prepared to pass through a 2-mm sieve were transferred into retaining rings that were seated on the ceramic plate cells. The soil sample was leveled in the ring and covered with squares of waxed paper. The ceramic pressure plate cells were placed in pans, where enough water was added to cover the surface of the plate with just a little excess. The system was allowed to stand for 48 hours to insure complete saturation of the soil. The plates were next mounted in the extractor using plastic spacers to separate the ceramic plate cells. Pressure in the extractor was gradually applied until equilibrium was attained at 15-bars or 220 psi. Equilibrium was attained when the burettes connected to each outflow tube did not show any volume change of the extracted liquid.

In a similar fashion, air-dried samples screened through a 2 mm sieve were used to determine the values for 15-bar water retention of the dried samples.

The 1/3-bar water retention was determined in a similar manner as outlined in method 4B1 and 4B1a in SSIR No. 1 (SCS, USDA, 1972).

Correlation and Reclassification

The proposed reclassification scheme of Smith (1978) was tested by first classifying the six selected soils. Necessary revisions of definitions and changes were made to fit the requirements of the new soil order with the selected Andepts in classifying them down to the lower categories. With the experience from the above exercise, flow-diagram keys were developed for the order Andisols from suborder to subgroup level (Appendix C). The flow-diagram keys were further tested by reclassifying 16 other soil series of Andepts having laboratory data and morphological descriptions in SSIR No. 29 (SCS, USDA, 1976).

In the process of using the keys, diagnostic limits between certain soils that key out in the same category but known to behave differently were identified. Efforts were made to prepare satisfactory definitions of some proposed diagnostic properties. Other criteria were redefined to permit a better placement of the soils where they properly belong.

The 64 soil series of Andepts in the State of Hawaii were then finally reclassified into the proposed order Andisols by using the flow-diagram keys.

RESULTS AND DISCUSSION

Classification into Proposed Order Andisols

Diagnostic Horizons

Based on existing soil descriptions and laboratory data, the Hilo, Akaka, and Kukaiau soils possess an umbric epipedon and a cambic subsurface horizon. The color value, moist, is 3 or less and the organic carbon content is more than 3 percent in the upper 18 cm. Profiles of these soils are shown in Figs. 3, 4, 5, and 6.

The three Waimea soils, on the other hand, have a mollic epipedon and a cambic subsurface horizon. The color value, moist, and the organic carbon content are similar to the above soils.

The cambic horizon is characterized by the presence of the very fine sand and finer textures in the fine earth fraction and by the presence of soil structure in more than half the volume. There are evidences of alteration, such as decreasing amount of organic carbon with depth and decreasing chroma and less red hue in the underlying horizons.

Bulk Density

Presented in Tables 1 through 6 are the bulk density values (Saran-coated clod method) of the soils. The Akaka and Kukaiau soils have $Db_{1/3}$ less than 0.85 g/cc, but the surface horizons of Hilo (0-17 cm) and Waimea (0-18 cm) have 0.85 g/cc or a slightly higher value. However, because the major part of the required depth may also be considered for reclassification, (Item 2 of Smith's, 1978 definition of Andisols), all

Fig. 3. Profile of Hilo soil located in Papaikou Quadrangle (about 19.5 km north of Hilo State Highway 19) on the Island of Hawaii, Hawaii County, Hawaii.

Fig. 4. Profile of Akaka soil located in Akaka Quadrangle (about 91 m east of the Akaka Falls Park parking lot on State Highway 22) on the Island of Hawaii, Hawaii County, Hawaii.

Fig. 5. Profile of Kukaiau soil located on the Island of Hawaii, Hawaii County, Hawaii, approximately 2.5 km SE of the town of Honokaa in the plantation of Honokaa Sugar Company.

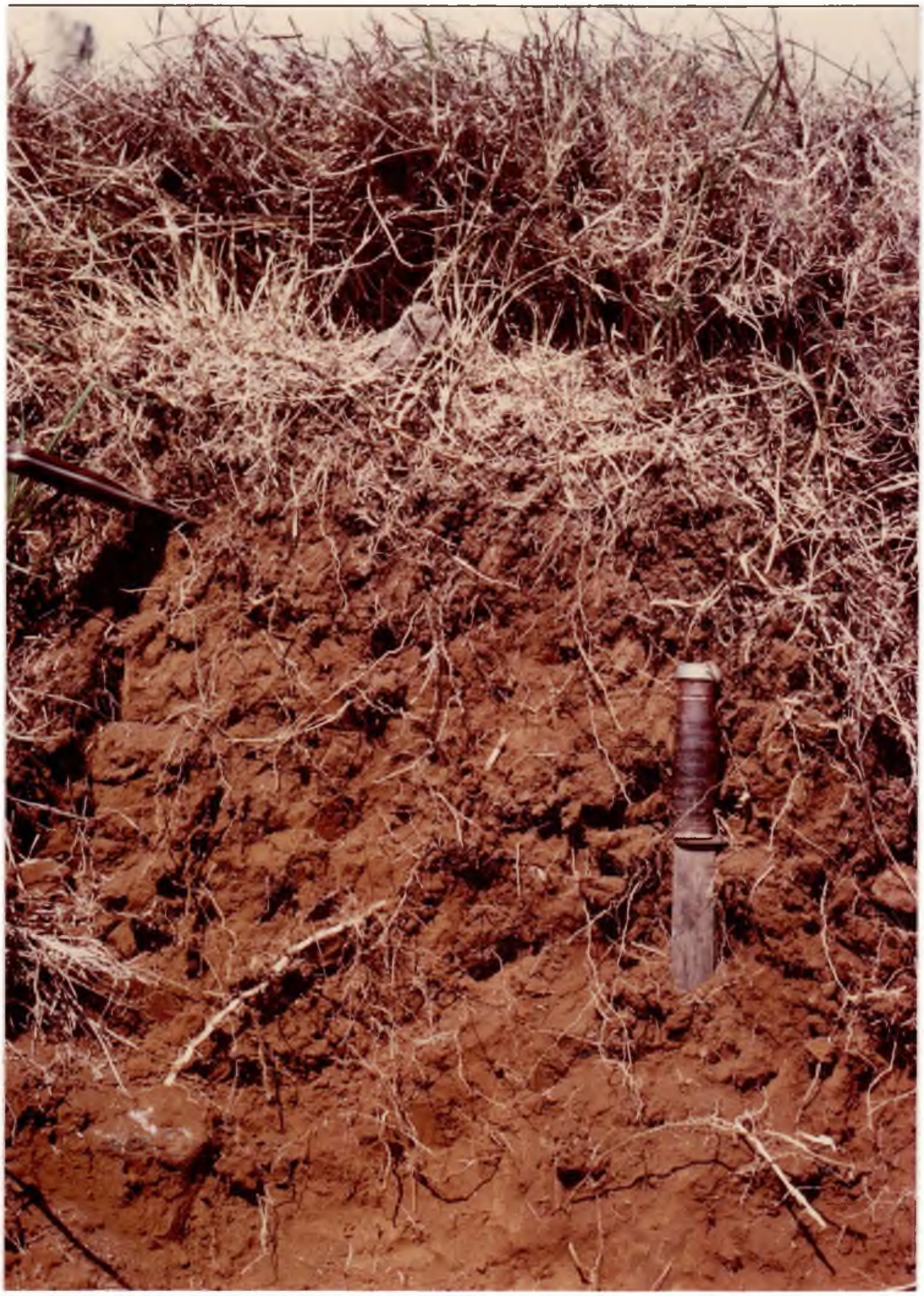

Fig. 6. Profile of Waimea soil located on the Island of Hawaii, Hawaii County, Hawaii.

TABLE 1. - Selected physical and chemical data of Hilo silty clay loam

Depth	Horizon	Bulk Density		Water Retention			
				Undried		Air Dried	
				.3 Bar	15 Bars	.3 Bar	15 Bars
-cm-		---g/cc----		------------pct-----------			
0-17	Ap	0.85	0.88	65.3	51.8	52.1	45.5
17-39	B21	0.49	0.39	148.0	126.7	71.1	64.8
39-65	B22	0.37	0.32	225.5	189.0	144.1	133.7
65-70	IIC	0.35	0.33	216.2	176.0	128.2	118.7
70-85	IIIAb1	0.34	0.34	232.5	190.9	145.7	135.1
85-110	IIIAb2	0.32	0.31	239.2	194.5	114.4	104.2
110-125	IIIAb21b	0.33	0.34	237.9	183.0	114.8	112.8

Depth	pH				Phosphate Retention
	NaF	H_2O	KCl	(KCl - H_2O)	
-cm-					---pct---
0-17	9.7	4.9	4.7	-0.2	90
17-39	8.7	5.4	4.9	-0.5	97
39-65	10.5	6.0	5.6	-0.4	99
65-70	10.8	6.2	5.8	-0.4	99
70-85	10.7	6.3	5.7	-0.6	99
85-110	10.7	6.1	5.8	-0.3	99
110-125	10.2	6.3	6.0	-0.3	99

TABLE 2. - Selected physical and chemical data of Akaka silty clay loam

Depth	Horizon	Bulk Density		Water Retention			
				Undried		Air Dried	
		Db_f	$Db_{.3}$	.3 Bar	15 Bars	.3 Bar	15 Bars
--cm--		----g/cc----		------------pct-------------			
0-25	Ap	0.68	0.35	89.9	55.6	54.7	46.6
25-60	B21	0.28	0.28	313.3	239.9	132.1	127.2
60-85	B22	0.25	0.28	309.9	237.5	161.1	160.9
85-95	IIApb	0.26	0.26	308.8	239.2	164.9	154.9
95-105	IIB21b	0.30	0.30	330.2	265.1	179.6	175.8
105-120	IIB22b	0.23	0.25	330.8	251.7	174.1	166.1

Depth	pH				Phosphate Retention
	NaF	H_2O	KCl	(KCl - H_2O)	
--cm--					---pct---
0-25	10.4	4.8	4.7	-0.1	99
25-60	10.4	5.3	4.9	-0.4	99
60-85	10.1	5.4	5.0	-0.4	99
85-95	10.5	5.2	5.4	0.2	99
95-105	10.1	5.2	5.5	0.3	99
105-120	10.0	5.4	5.5	0.1	99

TABLE 3. - Selected physical and chemical data of Kukaiau silt loam

Depth	Horizon	Bulk Density		Water Retention			
				Undried		Air Dried	
		Db_f	$Db_{.3}$	.3 Bar	15 Bars	.3 Bar	15 Bars
-cm-		----g/cc----		------------pct------------			
0-22	Ap	0.83	0.70	76.5	57.7	63.6	51.1
22-43	B21	0.50	0.47	156.4	116.7	99.0	89.4
43-66	B22	0.46	0.45	160.9	137.6	102.3	92.1
66-80	B23	0.45	0.46	161.2	130.1	108.4	98.9
80-97	B24	0.50	0.51	141.0	113.5	97.1	86.5
97-118	B25	0.49	0.47	142.9	113.9	93.1	81.9

Depth	pH				Phosphate Retention
	NaF	H_2O	KCl	(KCl - H_2O)	
-cm-					---pct---
0-22	10.4	4.9	4.8	-0.1	99
22-43	10.8	6.1	5.9	-0.2	99
43-66	10.6	6.1	6.0	-0.1	99
66-80	10.6	6.2	5.8	-0.4	99
80-97	10.5	6.1	6.1	0.0	99
97-118	10.3	6.3	5.9	-0.4	99

TABLE 4. - Selected physical and chemical data of Waimea very fine sandy loam

Depth	Horizon	Bulk Density		Water Retention			
				Undried		Air Dried	
		Db_f	$Db_{.3}$	.3 Bar	15 Bars	.3 Bar	15 Bars
-cm-		----g/cc----		-------------pct------------			
0-18	A11	0.97	0.85	53.1	32.2	56.7	32.6
18-40	A12	0.79	0.76	59.0	36.4	58.3	36.6
40-71	B21	0.80	0.77	62.0	40.5	59.8	39.7
71-99	B22	0.83	0.77	63.3	38.7	61.5	38.0
99-127	C1	0.83	0.80	64.5	36.9	63.4	35.1

Depth	pH				Phosphate Retention
	NaF	H_2O	KCl	(KCl - H_2O)	
-cm-					---pct----
0-18	9.0	6.7	5.9	-0.9	79
18-40	9.5	7.2	6.0	-1.2	80
40-71	9.5	7.7	6.7	-1.0	81
71-99	9.4	7.7	6.8	-0.9	73
99-127	9.4	7.7	6.6	-1.1	65

TABLE 5. - Selected physical and chemical data of Waimea loam

Depth	Horizon	Bulk Density*		Water Retention			
				Undried		Air Dried*	
		Db_f	$Db_{.3}$	.3 Bar	15 Bars	.3 Bar	15 Bars
-cm-		----g/cc----		----------pct----------			
0-18	Ap	0.69	-	68.1	29.1	-	33.6
18-36	B21	0.72	-	59.9	22.7	-	24.2
36-61	B22	0.60	-	70.8	42.6	-	33.8
61-99	B23	0.81	-	56.0	34.3	-	22.4
99-132	B24	0.66	-	69.9	43.6	-	23.9
132-152	C	1.09	-	41.9	20.9	-	20.0

Depth	pH				Phosphate Retention
	NaF	H_2O*	KCl*	(KCl - H_2O)*	
-cm-					---pct---
0-18	9.9	6.0	5.2	-0.8	70
18-36	10.3	7.1	6.3	-0.8	86
36-61	10.0	7.3	6.4	-0.9	72
61-99	10.2	7.5	6.6	-0.9	78
99-132	10.4	7.7	6.7	-1.0	86
132-152	10.8	7.8	7.0	-0.8	78

* Source: Ikawa et al. (unpublished).

TABLE 6. - Selected physical and chemical data of Waimea silt loam

Depth	Horizon	Bulk Density*		Water Retention			
				Undried		Air Dried	
		Db_f	$Db_{.3}$	.3 Bar	15 Bars	.3 Bar	15 Bars
-cm-		----g/cc----		------------pct------------			
0-18	Ap	-	-	47.1	31.7	-	-
18-25	B1	0.66	-	73.1	52.4	-	-
25-51	B21	0.84	-	66.6	48.9	-	-
51-81	B22	0.77	-	57.9	40.2	-	-

Depth	pH				Phosphate Retention
	NaF	H_2O*	KCl*	(KCl - H_2O)*	
-cm-					---pct---
0-18	9.3	5.4	4.7	-0.7	58
18-25	9.6	6.1	5.2	-0.9	75
25-51	9.7	6.2	5.3	-0.9	62
51-81	9.8	6.2	5.3	-0.9	60

* Source : Ikawa et al. (unpublished)

of the selected soils have $Db_{1/3}$ less than 0.85 g/cc and meet the bulk density requirement of Andisols.

The low bulk density of the volcanic ash soils is associated essentially with the porous character of the volcanic ash (Kanno, 1962). It may also be due to the high organic matter content of these soils (Swindale, 1965).

The data also show higher Db_f values in the Ap horizons. Perhaps the increase in bulk density is due to shrinkage resulting in a decrease in specific surface on account of drying of the soil.

There have been proposals to change the requirements of the bulk density by raising its limit from 0.85 g/cc to 0.9 or 1.0 g/cc (Furuhata and Amano, 1979; and Williams, 1979, ICOMAND Circular No. 1). They believe that the value of 0.85 g/cc was too low and that the two decimal places gave more emphasis on precision than is practical.

These proposed changes do not improve the classification of the selected soils of Hawaii.

Exchange Complex Predominantly Short Range Order Material (ECPSROM)

In addition to the low bulk density, the predominance of short range order materials (SROM) in the exchange complex is expressed in terms of a pH >9.4 with 1 M NaF, a phosphate retention value >90 percent, and a ratio of variable charge to CEC >0.7 (Blakemore's proposal, 1978, as attached to ICOMAND Circular No. 1).

Bulk Density - The required conditions for bulk density in ECPSROM is the same as that in the proposed definition of Andisols as discussed earlier. With regard to the procedures used, the Db values using Saran and Paraffin Methods showed no significant difference when compared by the paired t-test (table 7).

pH in NaF - The pH_{NaF} is another indicator of the dominance of SROM in the exchange complex.

The values of pH_{NaF} in tables 2, 3, and 6 show that Akaka, Kukaiau and Waimea loam soils met the required pH >9.4 in all horizons. Although the 17-39 cm horizon of Hilo, and the 0-18 cm horizon of both Waimea fine sandy loam and Waime silt loam have pH_{NaF} <9.4, they still qualified as Andisols because the major part of the required depth is pH_{NaF} >9.4 (tables 1, 4, and 6). Item 2 of Smith's definition admits this situation which is actually intended for the soils formed in thick deposits of volcanic ash but have low SROM at the surface horizons.

The use of fluoride to determine the predominance of SROM in the exchange complex have been questioned by some ICOMAND members. The problem narrow down to the unsettled question on the definition of the term "amorphous material." One contention was that of Parfitt (1978) who showed that SROM are dominated by active (Fe)-OH and (Al)-OH groups on surfaces, so that there will be reactions with fluoride wherever these groups are present, not only in Andisols. Perrott et al. (1976) also reported strong fluoride reactions with disordered aluminum oxides and aluminum silicates. More specific instances are the conflicting reports on the amount of allophane in selected Andepts of Hawaii (Tamura et al. 1953; Voss, 1970; Hudnall, 1977).

Hudnall concluded that none of the selected soils developed from volcanic ash in the island of Hawaii contained allophane. Chan (1972) described these non-crystalline, allophane-like materials to be amorphous

TABLE 7. - Bulk density at field state (Db_f) of selected soils determined by paraffin- and saran coated clod methods

Soil	Depth (cm)	Horizon	Paraffin Method	Saran coated clod Method
HILO	0-17	Ap	0.94	0.85
	17-39	B21	0.39	0.49
	39-65	B22	0.37	0.37
	65-70	IIC	0.35	0.35
	70-85	IIIAb1	0.34	0.34
	85-110	IIIAb2	0.34	0.32
	110-125	IIIAb21b	0.35	0.33
AKAKA	0-25	Ap	0.70	0.68
	25-60	B21	0.29	0.28
	60-85	B22	0.28	0.25
	85-95	IIApb	0.28	0.26
	95-105	IIB21b	0.28	0.30
	105-120	IIB22b	0.25	0.23
KUKAIAU	0-22	Ap	0.83	0.83
	22-43	B21	0.50	0.50
	43-66	B22	0.44	0.46
	66-80	B23	0.46	0.45
	80-97	B24	0.55	0.50
	97-118	B25	0.37	0.49
WAIMEA	0-18	A11	0.93	0.97
	18-40	A12	0.82	0.79
	40-71	B21	0.82	0.80
	71-99	B22	0.84	0.83
	99-127	C1	0.88	0.83

hydrated aluminum which Wada et al. (1976) showed by electron micrographs to be the non-crystalline hydrous alumina possessing very fine but well defined structure that corresponded to the characteristics of imogolite tubules.

Despite these conflicting opinions, the importance of pH_{NaF} in the proposed classification can not be over emphasized. The pH_{NaF} appears to be the only chemical parameter of ECPSROM that can separate the Andisols from the Oxisols (ICOMAND Circular No. 1, page 8). On the other hand, Leamy reported that many spodic horizons meet all the requirements of ECPSROM including the pH_{NaF}. The Andisols, however, can be separated from the Spodosols by the Fe and Al extracted by pyrophosphate at pH 10 which should be half or more of that extracted by citrate-dithionate for the latter.

Further Discussions on pH_{NaF}

pH_{NaF} at Different Soil Moisture Conditions - It is the rule of thumb not to dry volcanic ash soils prior to analysis due to the irreversible effect of drying on their physical and chemical properties. Nevertheless, the normal procedure is to determine pH_{NaF} of air dry sample (SCS, USDA, 1972). This prompted a preliminary assessment of the possible magnitude of variation of pH_{NaF} of undried, air-dried and oven-dried samples. The highest pH values were found in the undried condition, followed by the air-dried and oven-dried in decreasing order (Table 8). The differences in pH values were highly significant when evaluated by the paired t-test. What happens, is that: "crystallites of gibbsite are there in the wet state but separated from one another

TABLE 8. - The pH_{NaF} of 1 g soil measured at different moisture state of Hilo and Akaka soils in 2- and 60 minutes

Soil	Horizon	2 Min.			60 Min.		
		OD	AD	UD	OD	AD	UD
HILO	Ap	9.5	9.7	9.8	10.7	10.6	10.9
	B21	8.7	8.9	9.3	9.3	9.4	10.2
	B22	9.7	10.5	10.6	10.9	11.2	11.2
	11C	10.7	10.8	11.0	11.4	11.2	11.7
	IIIAb1	10.5	10.7	10.9	11.3	11.2	11.7
	111Ab2	10.3	10.4	10.9	11.2	11.1	11.7
	IIIAb21b	10.1	10.2	10.8	11.1	11.1	11.7
AKAKA	Ap	10.1	10.4	10.8	11.2	11.3	11.6
	B21	10.0	10.4	10.9	11.1	11.5	11.7
	B22	10.0	10.1	11.1	11.0	11.4	11.8
	11Apb	9.8	10.5	11.0	11.0	11.4	11.8
	11B21b	9.7	10.1	11.0	10.9	11.3	11.8
	11B22b	9.6	10.0	10.9	10.9	11.3	11.3

OD = oven dry sample

AD = air dry sample

UD = undried sample

by water, organic matter and other inorganic materials. As the soil dries, water loss allows the crystallites to come together into "pockets" or clusters of crystallites that tend to exclude or push out the organic matter. Upon complete drying, the soil consists of a mosaic of gibbsite crystallite clusters in a matrix of organic matter, other inorganic matter, and gibbsite crystallites, (Jones, R.C., personal communication).

The degree of pH_{NaF} reduction on drying, however, was not large enough to disqualify any of the soils studied. Nevertheless, this change due to moisture differences may become an important consideration for soils that are almost on the border line of being excluded from the requirement of the soil order Andisols, especially those soils with relatively low SROM contents. This conforms with the suggestion to use field-moist soil samples rather than air-dried soil in carrying out pH_{NaF} measurements on volcanic ash soils (Blakemore, 1980, ICOMAND Circular No. 2).

Weight of Soil for pH Determination

The weight of soil required for the pH_{NaF} determination in the definition of Andisols is 1 g of fine earth in 50 ml of 1 N NaF. It is well known, however, that the water content of some Andisols is extremely high and very variable, but the required weight is not specific as to whether it is the air-, fresh-, or oven-dry weight equivalent.

Comparison of pH_{NaF} values at air-dried and oven-dried weight equivalents was made. A highly significant difference was obtained by the paired t-test (Table 9). It was observed that the pH values of the soils with relatively low 15-bar water content increased dramatically when the weight was on the oven-dry equivalent. The magnitude of

TABLE 9. - The pH_{NaF} of 1 g air dry sample and 1 g oven dry weight equivalent measured at 2- and 60 minutes

Horizon	Depth	2 Minutes		60 Minutes	
		Air Dry	Oven Dry Equiv.	Air Dry	Oven Dry Equiv.
HILO					
Ap	0-17	9.7	9.8	10.6	10.8
B21	17-38	8.9	9.2	9.4	9.9
B22	38-65	10.5	10.8	11.2	11.3
11C	65-70	10.8	10.9	11.2	11.4
111Ab1	70-85	10.7	11.0	11.2	11.4
111Ab2	85-110	10.4	10.7	11.1	11.2
111Ab21b	110-125	10.2	10.5	11.1	11.2
AKAKA					
Ap	0-25	10.4	10.6	11.3	11.3
B21	25-60	10.4	10.6	11.5	11.4
B22	60-85	10.1	10.4	11.4	11.4
11Apb	85-90	10.5	10.6	11.4	11.4
11B21b	95-105	10.1	10.4	11.3	11.3
11B22b	105-120	10.0	10.2	11.3	11.2
KUKAIAU					
Ap	0-22	10.4	10.6	11.0	11.3
B21	22-43	10.8	11.0	11.1	11.4
B22	43-62	10.6	10.9	11.1	11.4
B23	62-98	10.6	10.9	11.1	11.3
B24	98-129	10.5	10.9	11.0	11.3
B25	129-158	10.3	10.8	11.0	11.3
WAIMEA					
A11	0-18	9.0	9.6	9.6	10.2
A12	18-40	9.5	10.0	9.9	10.5
B21	40-71	9.5	10.1	9.9	10.5
B22	71-99	9.4	10.1	9.9	10.5
C1	99-127	9.4	10.0	9.8	10.4

increase in pH was striking with soils having higher 15-bar water retention capacities. Non-crystalline substances which can flow, coalesce and form contact angles with other materials vary in specific surface with dehydration (Uehara and Gillman, in press). In this case, the oven-dry weight equivalent of soil will give more soil to compensate for the lose in specific surface with dehydration.

From this experience, it may be proposed that the pH_{NaF} of soils having 15-bar water retention values less than 40 percent should be measured at 1 g oven-dry weight equivalent to accommodate volcanic ash soils in drier areas.

Phosphate Retention - The required phosphate retention value that indicates predominantly SROM in the exchange complex is >90 percent. This parameter of ECPSROM differentiates SROM from organic materials where the former have a higher P-retention value.

Tables 1 through 3 show that Hilo, Akaka, and Kukaiau soils exceeded the 90 percent limit.

(Uehara and Gillman, in press) described the high phosphate retentive capacity of the Hydrandepts as the ability of the soil to occlude phosphorus due to their highly hydrated conditions which cause the surface with adsorbed phosphorus to coalesce with another surface resulting to the occlusion of phosphorus. Silva and Fox, (1974) found that the high P-sorption capacity of the Hydrandepts was due to their large content of SROM that are low in silica. They believe, however, that coatings of SROM (gel hulls) described by Jones and Uehara (1973) control the initial reactions of phosphate in many highly weathered soils. Silva and Fox presumed that phosphate sorption involved ligand exchange reactions between H_2PO_4 and the OH^- groups of aluminum and iron hydroxide surfaces in these soils.

The three Waimea soils on the other hand, continued to indicate lower SROM content from their P-retention values less than 90 percent.

One possible explanation for the low P-retention capacities of these soils is the fact that the higher soil pH and the more negative ΔpH values of the Waimea soil relative to the Hydrandepts (Hilo and Akaka) and the Dystrandepts (Kukaiau) result in a higher net negative charge. According to Uehara and Keng (1975) a soil is a cation exchanger if the pH is higher than the pH at the zero point of charge.

There have been similar reports that some Andisols in Chile could not satisfy the 90 percent P-retention requirement because of the possibility of imogolite as the dominant material in the exchange complex (ICOMAND Circular No. 1, page 9) hence, the suggestion to lower the requirement to 80 percent. The suggested P-retention limit is still too high for the Eutrandepts of Hawaii as demonstrated by the data in tables 4, 6, and 7.

Variable Charge - In the redefinition of ECDAM (Blakemore, 1978, as attached to the Andisol Proposal), the variable charge was calculated by subtracting the bases and exchangeable Al from the CEC obtained with $BaCl_2$ at pH 8.2. The CEC_{BaCl_2} at pH 8.2 is the sum of cations as defined in SSIR No. 1 (SCS, USDA, 1976). Subtracting the bases from the sum of cations gives the extractable acidity.

The reasons variable charge, as defined in the proposal is not suitable for the Andepts are as follows:

1. The equation (CEC_{BaCl_2} - Bases + Exch. Al = Variable Charge) by Blakemore assumes the bases and Al to be permanent charge (or ECEC).
2. The extractable acidity procedure in 4A5 and 6Hla of the SSIR No. 1 (SCS, USDA, 1972) cannot distinguish between variable and permanent charges.
3. The extractable acidity procedure does not apply to soils with high free salt or carbonate contents (Method 5A3, SSIR No. 1, USDA, 1972) such as the case of the Eutrandepts.

Thus, if the variable charge as presently defined, can not distinguish the variable from permanent charges and if the criterion cannot be used in all Andepts, then this definition is not valid for SROM. Parfitt (1979, ICOMAND Circular No. 1) also commented that: "the proposed ECDAM method for variable charge to give an estimate of H^+ retained at pH 8.2 does not differentiate between true exchangeable H^+ and H^+ adsorbed on the variable charge sites." Parfitt continued to criticize the proposed definition saying that the variable charge is dependent on the charge and concentration of the replacing ion and the pH of the zero point of charge (ZPC).

Water Retention at 15-Bars - The Hilo, Akaka, Kukaiau and one of the Waimea soils have water retention of undried fine earth at 15-bars pressure of more than 40 percent (Tables 1, 2, 3, and 7). On the other hand, the Waimea fine sandy loam and Waimea loam did not meet this requirement Tables 4 and 6).

Actually, item 4, page 8 of the proposed definition of Andisols is intended to accommodate the Eutrandepts of Hawaii (Smith, 1978).

Unfortunately, the diagnostic limit of 40 percent is too high. This strongly suggests that the water retention requirement should be modified or lowered to some value at least for the volcanic ash soils having ustic moisture regime. This conforms with the proposed revision to add in Item 4 the words, "an ustic moisture regime, and bulk density of fine earth fraction of less than 0.9" (ICOMAND Circular No. 1, p 3).

The 15-bar water retention values for the "wetter" soils (Hilo, Akaka and Kukaiau soils) decreased markedly on air drying, while they did not change for the "drier" soil (Waimea fine sandy loam). This may be explained by the work of Sherman (1957, 1958) who showed that the dehydration of the amorphous materials resulted in a decrease in the clay fraction and an increase in coarser fractions. This causes the lowering of the specific surface due to shrinkage of and cementation by non-crystalline substances (Uehara and Gillman, in press). The work by Tsuji *et al*. (1975), showed that Akaka soil in particular shrank in volume by as much as 50 percent when the moisture content was reduced from saturation to that at a suction of 300 cm. If the decrease in 15-bar water on drying is one expression of the influence of SROM, then the slight decrease of the 15-bar water content of Waimea fine sandy loam is again another indication that it could not qualify for the proposed soil order.

Classification to lower Categories and Proposal for Improvement of Classification

In strictly applying the proposed reclassification scheme by Smith (1978), the Waimea soils were excluded from the order Andisols. The

Hilo, Akaka, and Kukaiau soils were collectively keyed as Typic Hydrotropands, differing only in their soil temperature regimes at the subgroup level.

This suggests the need for improvement in the proposed reclassification scheme. Results of this study provide a realistic basis for making the necessary revisions to fit the proposed definition with the Andepts of Hawaii.

Suborder Category

When the proposed changes for 15-bar water retention and P-retention were applied, the Waimea soils (Eutrandepts) keyed out as Ustands, while the Hilo and Akaka (Hydrandepts) and Kukaiau (Dystrandepts) soils keyed out as Tropands.

Great Group Category

In the Great Group Category, the Hilo, Akaka, and Kukaiau soils all keyed out as Hydrotropands because they all have more than 100 percent 15-bar water retention of undried samples. The Hydrandepts and the Dystrandepts, however, are different (Soil Taxonomy pages 223-235). The former have clay that dehydrates irreversibly into aggregates of gravel and sand size, while the latter does not have. A revision of the definition of the Great Group Hydrotropands is thus necessary to achieve taxonomic separation of the two. The recommendation is to add after the words, "other Tropands that have 15-bar water retention of undried samples of 100 percent or more," <u>and have a SiO_2/Al_2O_3 molar ratio of $<$ 0.85 on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m</u>.

The Hydrandepts were retained as Hydrotropands and the Dystrandepts keyed as Haplotropands when the proposed criteria were applied. One advantage of using the SiO_2/Al_2O_3 molar ratio as a diagnostic property is its predictive value for some properties and behavior of soils.

Weathering is known to be largely a desilication process. Hence, a low SiO_2/Al_2O_3 molar ratio would indicate a more highly weathered soil. The degree of weathering relates to the mineralogy of the soil. The more weathered Andisols have pH_{KCl} that raises over that of the pH_{H_2O}, thus a positive ΔpH and a negative ΔpH for the less weathered soils. In another instance, the CEC of the Andisols is also influenced by the silica-sesquioxide ratio. In the process of dehydration, the greatest loss in CEC occurred in soils with low silica-sesquioxide ratio. The soils with higher ratio recovered considerably the lost CEC (Kanehiro and Sherman, 1956). These changes of CEC in Andisols relates to the lowering of specific surface caused by shrinkage of the non-crystalline substances.

Subgroup Category

In the key to subgroups of Haplustands, the subgroup name Ustollic should be changed to calcic for those soils that have a subhorizon within 1.5 m of the surface that contains soft, powdery secondary lime. The Typic subgroup will be one that has a mollic epipedon. The rationale is that the soils having mollic epipedon occur commonly in the somewhat cool regions with ustic moisture regime like the Eutrandepts. These soils should appropriately be the Typic subgroup of Haplustands. The presence of a calcic layer in some horizons of the Haplustands will be accounted for by introducing the Calcic subgroup.

In the key to subgroups of Vitrustands, Psammic will be dropped, the Mollic subgroup will be introduced, and the Typic subgroup will be redefined. Typic will be defined as: "Have more than 70 percent fine to coarse sand (0.1 to 2 mm), or more than 35 percent in volume, greater than 2 mm in some subhorizon within 1 m of the surface." The Mollic subgroup will be introduced to provide for the Vitrustands that usually have mollic epipedon.

The experience in Hawaii is that many Vitrustands commonly feel like sandy loam or loamy sand. To account for such characteristics of these "young" Andepts, the Psammic subgroup suggested in the proposal should be the Typic.

A positive ΔpH is of common occurrence in some horizons of some Hydrandepts and Dystrandepts. This unique property of these soils is recommended as a simple but useful criterion to distinguish the Acric subgroups of Hydrotropands. In this case, Acric should be redefined as: "Have a positive ΔpH in any horizon between 25 cm and 1 m or to a lithic or paralithic contact shallower than 1 m.

The ΔpH is a useful diagnostic property because it can indicate a soil that is dominated by variable charge minerals. It can also reveal the sign of the net electric charge of the soil material. If the ΔpH is positive, for instance, the material is an anion exchanger (Uehara and Keng, 1974). From the point of view of soil management, soils having positive ΔpH are distinctly different from those with negative ΔpH. For example, soils with a zero ΔpH has low affinity for monovalent ions and leaching losses is a problem. This property, therefore, should be reflected in their classification.

It was found that the ΔpH was correlated with the mean annual rainfall. The soils with positive ΔpH are those located in areas receiving >330 cm mean annual rainfall. These soils are the Acric Hydrotropands. Those having a zero or negative ΔpH are in areas receiving a mean annual rainfall <330 cm, and they are the Typic Hydrotropands. Since not all of the soil series have ΔpH data, this parameter was estimated based on this correlation and used as the basis for preliminary classification. There is thus, the need to determine the ΔpH of all Andisols of Hawaii to achieve more precise placement of the soil series. It is suggested that the subgroup Altic of the Hydrotropands be dropped. The reason is that, a high negative ΔpH will not indicate whether the charge is variable or permanent (Uehara, G., personal communication).

In the key to subgroups of Haplotropands, the Hydric and Typic Dystrandepts keyed out together as Typic Haplotropands because both have a SiO_2/Al_2O_3 molar ratio >0.85. However, the Hydric subgroup distinctly differs from the other Dytrandepts, because they are thixotropic in some horizons and have clay that dehydrates irreversibly into particles of sand and silt size (Soil Taxonomy, page 233). Hence, they should be separated at least at the subgroup level. In order to distinguish the Hydric from the Typic subgroups of Haplotropands, Hydric should be redefined as: "<u>Have a weighted average ratio of 15-bar water retention of undried sample of all horizons between 25 cm and 1 m or to a lithic or paralithic contact shallower than 1 m, to percent organic carbon in the upper 18 cm that is >10</u>." The Typic subgroup, therefore, will be those having a ratio <10. As defined earlier, Acric will be the soils having a positive ΔpH in any horizon between 25 cm and 1 m, or between 25 cm and a lithic or paralithic contact shallower than 1 m.

The depth criteria for organic carbon follows that of the depth requirement in the proposed definition of Andisols. The significance of using the 15-bar water retention is that: "The water retention seems to be a function of the amount of drying that has occurred in the soil during its formation, and the amount of amorphous clay produced by weathering" (Smith's proposal, 1978, page 2).

The ratio of 15-bar water retention to percent organic carbon was correlated with the mean annual rainfall. The Typic Haplotropands are confined to areas receiving a mean annual rainfall <130 cm, while the Hydric Haplotropands are those in areas having >130 cm. In cases where certain soil series did not have data on 15-bar water and organic carbon, the preliminary placement of these soils was made by consideration of this relationship. This demonstrated again the need for the determination of the ratio of 15-bar water content to percent organic carbon of the Andisols of Hawaii in order to achieve their precise placement in the new soil order.

There was difficulty in separating the Hydric from the Acric subgroups of Haplotropands, because both have a ratio of 15-bar water retention to percent organic carbon >10. In instances where no data on 15-bar water retention and organic carbon are available, it was suggested by G. Uehara (personal communication) that these soils can be placed as Typic until adequate data can be generated to make further evaluation.

Family Category

The proposal for definitions of classes of combinations of particle size and mineralogy applied very well with the reclassification of the

Andepts of Hawaii. For instance, the use of hydrous in place of thixotropic facilitated the classification because of the elimination of the subjective definition of thixotropic.

Reclassification of Selected Soils

The reclassification as a result of applying the proposed revisions is presented in table 10.

The "Trop" concept did not pose any difficulty in the classification of the selected soils. The Hilo, Akaka, and Kukaiau soils keyed out as Tropands, while the Waimea soils keyed out as Ustands.

To test further the adequacy of the proposed changes, 18 other soil series of Andepts with available laboratory data in SSIR No. 29 (SCS, USDA, 1976) were reclassified (Table 11). All soils were adequately accommodated by applying the proposed revisions.

It will be noted, however, that the selected Hilo soil in table 10 keyed out as Typic Hydrotropand because of a negative ΔpH in all horizons between 25 cm and 1 m. The Hilo soils in tables 11 and 12 on the other hand, were classified as Acric Hydrotropands on account of a positive ΔpH in some horizons.

Correlation of the Soil Series of the Andepts of the State of Hawaii With the Proposed Order Andisols

Table 12 presents the placement of the 64 soil series of Andepts recognized in the State of Hawaii in the proposed order Andisols. The placement was achieved with precision for the soil series that are complete with morphological, physical, mineralogical, and chemical data obtained from various sources (Loganathan, 1967; Oshiro, 1969; Hassan, 1969;and Cline, 1955). (These soils are identified by an asterisk in

TABLE 10. - Classification of selected soils based on the changes and revisions made on the proposed classification of soil order Andisols

Soil	Suborder	Great Group	Subgroup	Particle Size/Mineralogy and Soil Temperature
Hilo	Tropands	Hydrotropands	Typic Hydrotopands	Hydrous, isohyperthermic
Akaka	Tropands	Hydrotropands	Acric Hydrotropands	Hydrous, isomesic
Kukaiau	Tropands	Haplotropands	Typic Haplotropands	Hydrous, isothermic
Waimea	Ustands	Haplustands	Typic Haplustands	Medial, isothermic

TABLE 11. - Reclassification of some Andepts of Hawaii having available laboratory data based on the changes and revisions made on the proposed classification keys to the lower categories of order Andisols

Soil Series	In Soil Taxonomy*	In the Proposed Order Andisols
Naalehu	Typic Eutrandept, medial, isohyperthermic	Entic Haplustands, medial, isohyperthermic
Io	Typic Eutrandept, medial, over cindery, isothermic	Typic Haplustands, medial over cindery, isothermic
Pakini	Entic Eutrandept, medial, isohyperthermic	Entic Haplustands, medial, isohyperthermic
Waikaloa	Ustollic Eutrandept, medial, isothermic	Calcic Haplustands, medial isothermic
Waimea	Typic Eutrandept, medial, isothermic	Typic Haplustands, medial, isothermic
Apakuie	Typic Vitrandept, medial, isomesic	Entic Haplustands, medial, isomesic
Hilo	Typic Hydrandept, thixotropic, isohyperthermic	Acric Hydrotropands, hydrous, isohyperthermic
Akaka	Typic Hydrandept, thixotropic, isomesic	Acric Hydrotropands, hydrous, isomesic
Honokaa	Typic Hydrandept, thixotropic, isothermic	Typic Hydrotropands, hydrous, isothermic
Kealakekua	Typic Hydrandept, thixotropic, isothermic	Typic Hydrotropands, hydrous, isothermic
Hanipoe	Typic Dystrandept, medial, isomesic	Typic Haplotropands, medial, isomesic
Kaipoioi	Typic Dystrandept, medial, isomesic	Typic Haplotropands, medial, isomesic

* Source: Soil Survey Investigation Report No. 29 (SCS, USDA, 1976)

TABLE 11. (Continued) Reclassification of some Andepts of Hawaii having available laboratory data based on the changes and revisions made on the proposed classification keys to the lower categories of order Andisols

Soil Series	In Soil Taxonomy*	In the Proposed Order Andisols
Maile	Hydric Dystrandept, thixotropic, isomesic	Acric Haplotropands, hydrous, isomesic
Pane	Oxic Dystrandept, medial, isothermic	Typic Haplotropands, medial, isothermic
Honuaulu	Hydric Dystrandept, thixotropic over fragmental, isothermic	Acric Haplotropands, hydrous, over fragmental, isothermic
Paauhau	Hydric Dystrandept, thixotropic, isohyperthermic	Acric Haplotropands, hydrous, isohyperthermic

table 12). The placement of the other series was made in consultation with descriptions of particular pedons that have been characterized as representatives of the different series of Andepts (SCS, USDA, 1973). Other information was obtained from the Hawaii Soil Data Bank Computer Printout (1971). At the suborder level, the Hydrandepts, Dystrandepts and Placandepts keyed out as Tropands, while the Eutrandepts and Vitrandepts keyed out as Ustands.

TABLE 12. - Placement of Soil Series of the Andepts of the State of Hawaii in the proposed classification of Andisols

Suborder	Great Group	Subgroup	Family	Soil Series
USTANDS	Vitrustands	Typic Vitrustands	ashy Medial over cindery, isomesic	Huikau
		Umbric "	Medial, isomesic Uma	Apakuie* Typic
			ashy	~~Keekee~~ Uma
		Mollic "	over sandy-skeletal	Kilohana cindery, isomesic
		Mollic "	Medial, or sandy isohyperthermic	Alae
		~~Mollic Vitrustands~~	~~Medial, isomesic~~	~~Kamakoa~~
	Haplustands	Typic Haplustands	Medial, isothermic	Kikoni
				Kula
				Palapalai
				Waimea*
			Medial over cindery, isothermic	Io*
				Ulupalakua
			Medial over fragmental, isohyperthermic	Kainaliu
		Calcic Haplustands	Medial, isothermic	Kamaoa
				Waikaloa*
			Medial, isohyperthermic	Koko
				Oanapuka
			Medial, over fragmental, isothermic	Puu Pa*
			Medial, over fragmental, isohyperthermic	Kaalualua

* With complete laboratory data.

TABLE 12. (Continued) Placement of Soil Series of the Andepts of the State of Hawaii in the proposed classification of Andisols

Suborder	Great Group	Subgroup	Family	Soil Series
USTANDS	Haplustands	Entic Haplustands	Medial, isohyperthermic	Naalehu*
				Pakini*
		Lithic Haplustands	Medial, isohyperthermic	Kalaupapa
				Waiaha
TROPANDS	Placotropands	Ruptic Placotropands	Hydrous, isomesic	Kahua
	Hydrotropands	Typic Hydrotropands	Hydrous, isomesic	Piihonua
			Medial over thixotropic, isomesic	Puaulu*
			Hydrous, isothermic	Alapai*
				Honaunau
				Honokaa*
				Kailua
				Kealakekua*
				Hana
		Acric Hydrotropands	Hydrous, isomesic	Akaka*
			Hydrous, isothermic	Honomanu
				Kaiwiki
				Ohia
			Hydrous, isohyperthermic	Hilo*
			Hydrous over fragmental, isohyperthermic	Olaa
		Lithic Hydrotropands	Hydrous, isothermic	Hilea
			Hydrous, isohyperthermic	Panaewa

TABLE 12. (Continued) Placement of Soil Series of the Andepts of the State of Hawaii in the proposed classification of Andisols

Suborder	Great Group	Subgroup	Family	Soil Series
TROPANDS	Haplotropands	Typic Haplotropands	Medial, isomesic	Hanipoe*
				Kaipoioi*
				Kapapala
				Laumaia
				Olinda
			Medial over cindery, isothermic	Tantalus
			Hydrous, isothermic	Kukaiau
				Moaula
			Medial, isothermic	Oli
				Paaiki
				Pane
		Acric Haplotropands	Hydrous, isomesic	Maile*
			Hydrous, isothermic	Niulii*
			Hydrous over fragmental, isothermic	Honuaulu*
			Hydrous, isohyperthermic	Ookala
				Paauhau*
		Hydric Haplotropands	Medial, isomesic	Umikoa*
			Medial, isothermic	Manu
			Hydrous, isomesic	~~Mahana~~
				Punohu
				Puu Oo
		Lithic Haplotropands	Hydrous, isomesic	Puukala*
			Medial, isothermic	Puhimao
				Heake

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SUMMARY AND CONCLUSIONS

Six selected soils of Andepts were characterized and reclassified into the new soil order Andisols in accordance with the proposed classification scheme by Smith (1978). The results from using Smith's reclassification on these soils are as follows:

1. All of the six soils possess the morphological characteristics that are diagnostic for the proposed soil order Andisols. The Tropands have umbric epipedon underlain by a cambic horizon while the Ustands have a mollic epipedon and a cambic subsurface horizon.
2. In terms of the bulk density requirements, the Akaka and Kukaiau soils qualified as Andisols by virtue of Item 1 of the proposed definition of Andisols. The Hilo and Waimea soils fulfilled the requirements by Item 2 which is intended for the Andisols having thick deposit of volcanic ash but low in short range order material at the surface horizon.
3. The pH_{NaF} test for short range order materials adequately applied to all soils.
4. The P-retention requirement for an exchange complex dominated by SROM was met by the Hilo, Akaka and Kukaiau soils but was too high for the Waimea soils.
5. The water retention of undried fine earth of 40 percent or more at 15-bars tension as required in Item 4 is suitable for Hilo, Akaka and Kukaiau soils but too high for the Waimea soils.

The result presents two alternatives in deciding the fate of the Waimea soil. One is to accept the proposed definition of soil order

Andisols and exclude the Waimea soils from this soil order. The other is to make some revisions that would enable the definition to accommodate the Waimea soil.

Considering the first case, the data from the Waimea soil reveal that they fall short of the P-retention and the 15-bar water retention requirements and they barely meet the pH_{NaF} requirement.

In the soil order Andisols, the predominance of SROM in the exchange complex is indicated by a pH_{NaF} >9.4, a 15-bar water retention >40 percent, and a P-retention >90 percent. A low $Db_{1/3}$ like the three above properties is an accessory property that reflects a high specific surface.

While some non-crystalline materials are present in the Waimea soil, it is mainly halloysitic in mineralogy (Hudnall, 1977). The relatively low specific surface of halloysite and the high base saturation of the soil perhaps account for the failure of the Waimea soils to meet the chemical requirements for the soil order Andisols.

The low P-retention capacity of the Waimea soils has been confirmed by earlier studies showing the low P-adsorption capacity of the Eutrandepts (Waimea soil) relative to other soils developed from volcanic ash (Fox, 1974 and Fox and Searle, 1978).

While a P-retention value <90 percent is permitted with the Haplustands (Item 4 of Smith's proposal), the 15-bar water retention >40 percent still excludes the Waimea soil from the Andisols. If the Waimea soil is not an Andisol, it appears to be best accommodated in the order Mollisols and Great Group Haplustoll. However, this is not permitted because the strict definition of Mollisols excludes soils with bulk densities <0.85 g/cc . The authors of Soil Taxonomy probably included this restriction to exclude Andepts with mollic epipedon from the Mollisols.

In the second option, the Waimea soils may be accommodated into the new order by merely revising item 4 of the proposed definition of the Andisols. The revision simply requires a 15-bar water retention of undried fine earth of 40 percent or more; or (in the proposed definition, the wording here is "and") a ratio of 15-bar water percentage (undried) to the meq of exchangeable bases is 1.5 or less; and (in the proposed definition, the wording here is "or") the pH of 1 g of fine earth is 50 ml of 1 N NaF is 9.4 or more after 2 minutes.

Although the Waimea soil is chemically marginal, with regards to ECPSROM, because of its high base and halloysite content, the soil physically behaves very much like the Andisols. For this reason, its placement in the Andisol order is preferred.

On the basis of this work, some recommendations for amending the Andisol classification system were made.

Variable Charge

The variable charge as a criterion for ECPSROM needs further study. The principle involved in its measurement seems doubtful because the procedure used to determine the variable charge is not capable of distinguishing the variable from the permanent charges. For soils like the Ustands, which frequently have high base saturation and short range order materials, the definition leads to an incorrect result about the nature of the charge characteristics. Hence, it should not be used as a criterion for ECPSROM.

Key to Great Groups of Tropands

The definition of Hydrotropands should be amended in order to separate the Hydrandepts from the Dystrandepts. The amendment should be made on page 11, paragraph EB, line 2, after the words, "samples of 100 percent or more," add, and have a SiO_2/Al_2O_3 molar ratio of <0.85 on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m."

Key to Subgroups of Vitrustands

The Typic subgroup should be redefined as: "Have more than 70 percent fine to coarse sand (0.1 to 2 mm), or more than 35 percent in volume, greater than 2 mm in some subhorizons within 1 m of the surface."

The Psammic subgroup will be dropped and the Mollic will be introduced to account for the Vitrustands having mollic epipedon.

Key to Subgroups of Haplustands

The subgroup name Ustollic should be changed to Calcic but retain the definition as: "Have a subhorizon within 1.5 m of the surface that contains soft, powdery secondary lime."

The Typic subgroup will be one that has a mollic epipedon.

Key to Subgroups of Hydrotropands

The subgroup Altic should be eliminated. Acric subgroup is introduced instead, in order to account for the distinct positive ΔpH possessed by some Hydrotropands.

The Acric subgroup will thus be defined as: "Have a positive ΔpH in any horizon between 25 cm and 1 m or to a lithic or paralithic contact that is shallower than 1 m."

In this case, the Typic subgroup will be one that has a zero or a negative ΔpH.

Key to Subgroups of Haplotropands

Hydric - To separate the Hydric from the Typic subgroup, Hydric subgroups should be redefined as: "Have a weighted average ratio of percent 15-bar water retention of undried soil between 25 cm and 1 m or to a lithic or paralithic contact shallower than 1 m to percent organic carbon of the upper 18 cm that is >10."

The Typic subgroups are those with ratio <10.

Acric - The Acric subgroup will key together with Hydric subgroup because both will have a ratio of 15-bar water to percent organic carbon >10. The taxonomic separation of the two is made by redefining Acric as: "Have a positive ΔpH in some horizon between 25 cm and 1 m or to a lithic or paralithic contact that is shallower than 1 m." In this case the soils having a zero or a negative ΔpH will be the Hydric subgroups.

Suggestions on Methodologies

Based on experiences in this study, slight modifications of some of the methodologies are recommended to suit the laboratory characeriza- tion of soils developed from volcanic ash.

a. The pH_{NaF} should be determined on undried samples but expressed on an oven-dry weight basis.

b. If method 8C1d in SSIR No. 1 (SCS, USDA, 1972) is intended to test the amount of short range order materials in soils developed from volcanic ash, the first sentence in the procedure should be revised to read: "Place 1 g (oven dry equivalent) of <u>undried</u> soil in a 100 ml beaker . . . . ."

After testing the proposed reclassification scheme, the following general conclusions can be made:

1. The improvement made on the proposal led to a more adequate system of classifying Andisols.
2. All the Andepts of Hawaii qualified into the proposed order Andisols.
3. The reclassification of the Andepts could provide a better basis for interpreting soil surveys.

APPENDIX A

KEY TO SUBORDERS*

A. Andisols that have artificial drainage or an aquic moisture regime and have one or more of the following:

a. A histic epipedon

b. At a depth of less than 50 cm or immediately below an epipedon that has color values, of 3 or less, dominant colors, moist, on ped faces or in the matrix, if peds are absent, as follows:

1. If there is mottling, chroma of 2 or less.
2. If there is no mottling, chroma of 1 or less.
3. Distinct or prominent, coarse or medium mottles due to segregation of iron within or immediately below 18 cm of the surface of any Ap deeper than 18 cm with any chroma.

AQUANDS

B. Other Andisols that have a frigid or cryic temperature regime.

BORANDS

C. Other Andisols that have a xeric moisture regime,

XERANDS

D. Other Andisols that have an ustic moisture regime or a duripan, or both.

USTANDS

E. Other Andisols that have a thermic or colder temperature regime or an isofrigid temperature regime and a udic or perudic moisture regime: UDANDS

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*Source: ICOMAND (1979), Circular No. 1.

APPENDIX A (Continued)

F. Other Andisols: ORTHANDS

KEY TO GREAT GROUPS*

AQUANDS

AA. Aquands that have a duripan or a placic horizon that rests on a duripan.

DURAQUANDS

AB. Aquands that have a 15-bar water retention of previously dried samples of less than 15% on the weighted average of all horizons between 25 cm and 1 m and have less than 30% 15-bar water on undried samples of the same horizons.

VITRAQUANDS

AC. Other Aquands that do not have a placic horizon.

HAPLAQUANDS

BORANDS

BA. Borands that have an epipedon 30 cm or more thick with color values, moist, of 2 or less and chromas of less than 2 throughout, or have a subsurface horizon (a buried A_1) that meets these requirements and has an upper boundary within 30 cm of the surface if it is 30 cm thick, or has an upper boundary within 50 cm of the surface if it is 50 cm or more thick: and has 8% or more organic carbon throughout these thicknesses.

MELANOBORANDS

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*Source: ICOMAND (1979) Circular No. 1.

APPENDIX A (Continued)

BB. Other Borands that have a cryic or pergellic soil temperature regime.

CRYOBORANDS

BC. Other Borands that have a placic horizon within 1 m of the surface in half or more of each pedon.

PLACOBORANDS

BD. Other Borands that have 15-bar water retention of previously dried samples of less than 15% on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m and have less than 30% 15-bar water on undried samples of the same horizons.

VITRIBORANDS

BE. Other Borands.

HAPLOBORANDS

XERANDS

CA. Xerands that have a duripan or a placic horizon that rests on a duripan.

DURIXERANDS

CB. Other Xerands that have a 15-bar water retention of previously dried samples of less than 15% on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m and have less than 30% 15-bar water on undried samples of the same horizons.

VITRIXERANDS

CC. Other Xerands.

HAPLOXERANDS

APPENDIX A (Continued)

USTANDS

DA. Ustands that have a duripan.

DURUSTANDS

DB. Other Ustands that have 15-bar water retention of previously dried samples of less than 15% on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m and have less than 30% 15-bar water on undried samples of the same horizons.

VITRUSTANDS

DC. Other Ustands.

HAPLUSTANDS

TROPANDS

EA. Tropands that have a placic horizon within 1 m of the soil surface in half or more of each pedon.

PLACOTROPANDS

EB. Other Tropands that have 15-bar water retention of undried samples of 100% or more on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m.

HYDROTROPANDS

EC. Other Tropands that have a 15-bar water retention of previously dried samples of less than 15% on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact that is shallower than 1 m and have less than 30% 15-bar water on undried samples of the same horizons.

VITRITROPANDS

APPENDIX A (Continued)

ED. Other Tropands.

HAPLOTROPANDS

UDANDS

FA. Udands that have a placic horizon within 1 m in half or more of each pedon.

PLACUDANDS

FB. Other Udands that have a 15-bar water retention of undried samples of 100% or more on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact that is shallower than 1 m.

HYDRUDANDS

FC. Other Udands that have an epipedon 30 cm or more thick with color values, moist, of 2 or less and chromas of less than 2 throughout, or have a subsurface horizon (a buried A_1) that meets these requirements and has an upper boundary within 30 cm of the surface if it is 30 cm thick, or has an upper boundary within 50 cm of the surface if it is 50 cm or more thick; and has 80% or more organic carbon throughout these thicknesses.

MELANUDANDS

FD. Other Udands that have a 15-bar water retention of previously dried samples that is less than 15% on the weighted average of all horizons between 25 cm and 1 m and have less than 50% 15-bar water on undried samples of the same horizons.

VITRUDANDS

FE. Other Udands.

HAPLUDANDS

APPENDIX A (Continued)

PROPOSED SUBGROUPS IN ADDITION TO TYPIC*

AQUANDS
- Haplaquands
  - Allic
  - Entic
  - Hydric
  - Tropic
  - Ustic
  - Vitric
  - Xeric
  - Thapto-Histic
- Vitraquands
  - Allic
  - Entic
  - Tropic
  - Ustic
  - Xeric
  - Thapto-Histic

BORANDS
- Cryoborands
  - Allic
  - Placic
  - Pergelic
  - Tropic
  - Vitric
- Haploborands
  - Allic
  - Aquic
  - Entic
  - Placic
  - Vitric
- Melanoborands
  - Acric
  - Allic
  - Aquic
  - Cryic
  - Lithic
  - Pachic
  - Vitric

TROPANDS
- Haplotropands
  - Acric
  - Allic
  - Aquic
  - Entic
  - Hydric
  - Lithic
  - Oxic
  - Placic
  - Vitric
- Hydrotropands
  - Altic
  - Lithic
  - Placic
- Placotropands
  - Ruptic
- Vitritropands
  - Aquic
  - Allic
  - Entic
  - Lithic
  - Placic
  - Psammic

UDANDS
- Napludands
  - Allic
  - Aquic
  - Entic
  - Hydric
  - Lithic
  - Placic
  - Vitric
- Hydrudands
  - Altic
  - Lithic
  - Placic
- Placudands
  - Ruptic
- Vitrudands
  - Allic
  - Aquic
  - Entic
  - Lithic
  - Placic
  - Psammic

USTANDS
- Durustands
  - Vitric
- Haplustands
  - Aquic
  - Entic
  - Lithic
  - Ustollic
  - Vitric
- Vitrustands
  - Entic
  - Lithic
  - Psammic

XERANDS
- Durixerands
  - Vitric
- Haploxerands
  - Aquic
  - Entic
  - Lithic
  - Vitric
- Vitrixerands
  - Entic
  - Lithic
  - Psammic

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* Source: ICOMAND (1979) Circular No. 1.

APPENDIX A (Continued)

BORANDS
- Placoborands
  - Ruptic
- Vitriborands
  - Entic
  - Placic

UDANDS
- Melanudands
  - Acric
  - Allic
  - Aquic
  - Hydric
  - Lithic
  - Pachic
  - Vitric

SUBGROUPS DEFINITIONS*

The suggested wording of items in the definitions of typic subgroups to provide for the subgroups proposed in the various groups are as follows:

ACRIC To provide for this subgroup, the typic subgroup should be defined:

Have in all subhorizons between 25 cm and 1 m, extractable bases plus KCl extractable Al, expressed as Al^{3+}, that is 1.5 meq per 100 g fine earth or more when the sum of bases plus Al^{3+} is divided by

$$\frac{2.5 \times \%\ 15\text{-bar water (air dried)}}{100}$$

Explanation Extractable bases and KCl extractable Al are commonly very low in Andisols of humid regions because of the absence of any permanent charge in the amorphous colloids. The range in extractable cations in Andisols is from less than 0.2 meq to more than 50 meq in Ustands, and some provisions is needed for the soils with extremely low amounts of bases where Ca deficiencies create problems with root growth. Potential Al toxicities are also present, but quantities of cations can be so low

*Source: ICOMAND (1979), Circular No. 1.

that calculations of Al saturation are unreliable. The use of the 15-bar water percentage of dried samples multiplied by 2.5 is an attempt to adjust values for the amounts of clay present. This relationship was discussed earlier.

ALLIC To provide for this subgroup, the typic subgroup should be defined:

Have, in all subhorizons between a depth of 15 cm and 1 m, or, if an Ap is present, between a depth of 25 cm below the base of the Ap and 1 m, or between these depths and a lithic or paralithic contact shallower than 1 m, KCl extractable Al, expressed as Al^{3+}, that is less than one-third of the sum of extractable bases, if the sum of bases plus Al^{3+} is 1.5 meq or more when divided by

$$\frac{2.5 \times \%15\text{-bar water (air-dried)}}{100}$$

Explanation Most Andisols have only traces or no KCl extractable Al. The most common reasons for its presence are the presence of some crystalline clay and the use of acid forming fertilizers. Because the fertilizers can affect horizons just below the depth of fertilizer application, the presence of KCl extractable Al must be tolerated in cultivated soils below the Ap. If the sum of cations is very low, as in the acric subgroup, the ratio between bases and Al cannot be measured accurately. Therefore, Al saturation is proposed for use only if there are some tenths of a meq of cations present. The use of the 15-bar water percentage of air dried soil is an attempt to adjust absolute values for the amounts of clay present. The ratio proposed is for an Al saturation of 25 percent. Some will consider this too low.

APPENDIX A (Continued)

Some will consider that the Al saturation is not mappable. An alternative is to use the pH in water or KCl. A pH of 5.1 in water should be excluded from the typic subgroups. In the West Indies, a few questionable Andisols have pH values in water of as low as 4.7. These must be distinguished from typical Andisols by some means. Pedon 6 of Soil Taxonomy, with a pH of about 5.1 is about 80% Al saturated.

ALTIC To provide for this subgroup, the typic subgroup should be defined:

Have a negative ΔpH of 0.3 or less (pH KCl-pH H_2O) in some subhorizon within 1 m of the soil surface.

Explanation This subgroup is proposed only for hydric great groups. Most soils presently classified as Hydrandepts or as hydric subgroups of Dystrandepts have a net positive charge or no charge in deeper horizons. Negative charges in surface horizons seem to be due to organic matter than mineral colloids, and decrease with depth as the organic matter diminishes. At the same time, anion retention increases with depth, particularly of sulfates. This is considered typical. The altic subgroup (L altus, high, for high negative charge) is an extragrade provided for the hydric great group soils that have an appreciable negative charge at depth.

AQUIC To provide for this subgroup, the typic subgroup should be defined:

Do not have distinct or prominent medium or coarse mottles due to segregation of iron, or have mottles that have chromas of 2 or less,

APPENDIX A (Continued)

within 1 m of the soil surface if the mottled horizon is saturated with water at some season of the year or the soil is artificially drained.

Explanation Aquic subgroups are provided for the Andisols that are mottled at depth and that either have ground water in the mottled horizons or have been artificially drained. The loss of 15-bar water on drying tends to be high if expressed as the percentage of the 15-bar water of undried samples. Hence, the provision for hydric subgroups needs to be waived in aquic subgroups. It should be noted that high chroma mottles may be found at the contact between strongly contrasting particle size classes, but should not place soils in aquic subgroups because the contact will not meet the specifications for saturation with water.

CRYIC To provide for this subgroup, the typic subgroup should be defined:

Do not have a cryic temperature regime.

Explanation A cryic subgroup is provided only for Malanoborands, many but not all of which are cryic. The frigid is called typic so that the term cryic will appear in the name of all cryic soils. Most of the Cryic Melanoborands will probably be in a Cryic Tropic subgroup.

ENTIC To provide for this subgroup, the typic subgroup should be defined:

Have 5% or more organic carbon throughout the upper 25 cm or have a subsurface horizon that has an upper boundary within 30 cm or the surface (a buried A_1) that meets this requirement.

Explanation Entic subgroups are suggested because they are in Soil Taxonomy, but with very serious reservations. Color value is useless

APPENDIX A (Continued)

in Tropands and in soils formed in black cinders, lapilli, and some ashes, as a diagnostic, so carbon contents are substituted. It seems possible that the vitric subgroups can be substituted for the entic, and the latter dropped. The utility of this subgroup needs discussion. West Indian Tropands are commonly eroded and subsoils exposed by the practice of hoeing down slope. The entic subgroups would require different series for eroded and uneroded soils.

HYDRIC To provide for this subgroup, the typic subgroup should be defined:

Lose less than 75% of the 15-bar water of undried samples by air-drying on the weighted average (by thickness) of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m, and have less than 70% 15-bar water before drying.

Explanation Some soils in Haplic great groups approach the hydric great groups both in 15-bar water in undried samples and in the loss of 15-bar water on drying, if that is expressed as the percentage of the 15-bar water in the undried samples. The Patua loam of New Zealand would be an example. It has a mesic temperature and about 4 m of precipitation. The 15-bar water of undried samples is about 75%, and that of air-dried samples is 11%, a loss of 85% on drying. Hydrotropands lose about 80% of their 15-bar water on drying. The requirement of 70% 15-bar water in fresh samples introduced for the hydric subgroups by this item may not be needed, but it is suggested to eliminate the very slightly weathered ash. This provision should be waived in aquic subgroups, which also show a high loss of 15-bar water on drying.

APPENDIX A (Continued)

LITHIC To provide for this subgroup, the typic subgroup should be defined:

Do not have a lithic contact within 50 cm of the surface.

Explanation This item has been used throughout Soil Taxonomy except in Oxisols.

OXIC To provide for this subgroup, the typic subgroup should be defined:

Have in some subhorizon between 25 cm and 1 m, less than 30% 15-bar water in air dried samples if the sum of the bases plus KCl extractable Al, expressed as Al^{3+} is less than 2.5 meq per 100 g fine earth when divided by

$$\frac{2.5 \times \%\ \text{15-bar water (air dried)}}{100}$$

?

and if there is less than 10% weatherable minerals in the 0.2 to 0.02 mm fraction.

Explanation In warm humid climates, some Andisols in old tephra seem to grade into Oxisols with a loss of weatherable minerals, extractable cations, and of allophane or allophane-like clays. The latter are largely changing to halloysite and kaolin. Because these more completely weathered volcaniclastics lack much silt or sand, the 15-bar water in dried samples begin to approach 40%. Hence, the soils that have a high 15-bar water content after drying and that lack appreciable amounts of weatherable minerals and extractable cations are placed in oxic subgroups. The oxic subgroup is presently suggested only for Haplotropands.

PACHIC To provide for this subgroup, the typic subgroup should be defined:

APPENDIX A (Continued)

Have an umbric epipedon that is less than 1 m thick.

Explanation The umbric epipedon of soils in Melanic great groups may vary from a minimum of 30 cm to a maximum of 2 m or more. The thick epipedons commonly cover the entire landscape irrespective of the position in the landscape. They could represent slow accumulation of ash, but the evidence in the Andes is against this hypothesis. These, closely associated Mollisols formed in presumably the same ash may have a well developed argillic horizon in the upper third of a very thick mollic epipedon. This suggests stability rather than accumulation. No method of distinguishing pachic and cumulic subgroups seems practical, so no cumulic subgroup are suggested. There is a question about the thickness limit of the pachic subgroup. Perhaps 75 cm would be better than 1 m.

PERGELIC To provide for this subgroup, the typic subgroup should be defined:

Have a mean annual soil temperature higher than 0° Celcius.

Explanation This definition is the same as that in other kinds of soil in Soil Taxonomy.

RUPTIC PLACIC To provide for this subgroup, the typic subgroup should be defined:

Do not have an intermittent placic horizon within 1 m of the surface in more than one-fifth of the area of each pedon.

Explanation This subgroup is provided for soils that have an intermittent placic horizon in less than half of each pedon (the limit for placic great groups) but in more than one-fifth of the pedon. It is

APPENDIX A (Continued)

proposed to tolerate small areas of intermittent placic horizon in typic subgroups because they probably are not significant barriers to water movement or root growth. It is also proposed to permit, in typic subgroups incipient accumulations of iron in thin horizons if they are soft and plastic and do not interfere with roots.

RUPTIC SUBGROUPS OF PLACIC GREAT GROUPS To provide for these subgroups, the typic subgroup should be defined:

Have a placic horizon that is continuous throughout each pedon, or is present in 90% or more of each pedon.

Explanation While there are large areas of placic great groups in which the placic horizon is continuous, the presence of small areas within a placic horizon must be tolerated in typic subgroups. If the areas without a placic horizon become significant, ruptic subgroups are proposed, following the term ruptic with the name of the great group whose definition fits the soil where the placic horizon is absent. Thus, subgroup definitions would read: "like the typic except for (the above item), and . . . followed by identification of the appropriate great group."

PSAMMIC To provide for this subgroup, the typic subgroup should be defined:

Have less than 70% fine to coarse sand (0.1 to 2 mm), or more than 35%, in volume, greater than 2 mm in some subhorizons within 1 m of the surface.

Explanation This extragrade subgroup is provided for Andisols that are particularly subject to blowing and drifting. The definition is as

APPENDIX A (Continued)

nearly comparable to that of Psamments as is possible, but because of dispersion difficulties with Andisols and the vesicular nature of some of the sands, it is necessary to rely on sieving rather than sedimentation. Many pumiceous sands float in water. Pumice particles of gravel size, up to about 20 mm in the largest dimension, are found in coppice dunes mixed with andesitic ash fine and medium sands. However, in the least dimension, these gravels approach 2 mm in thickness. For the present, it seems adequate to sieve the less than 2 mm fraction.

TROPIC To provide for this subgroup, the typic subgroup should be defined:

Do not have an iso-temperature regime.

Explanation Tropic subgroups are proposed for Aquands and Cryoborands. The usage in Aquands is parallel to that in Aquepts. In Cryoborands, it seems essential because temperature is not specified in families of cryic great groups, but the potential uses of a cryic soil in mid- or high latitudes are very different from those in low altitudes. In intertropical regions, cryic soils have frost every night but in higher latitudes there is frost free growing season. Melanoborands that have an isofrigid temperature should be in a cryic tropic subgroup.

USTIC To provide for this subgroup, the typic subgroup should be defined:

If not irrigated, are not dry in some or all parts of moisture control section for as long as 90 cumulative days in most years.

Explanation Ustic subgroups are provided for Aquands as a temporary expedient pending revision of the definition of the ustic moisture regime for the wet and dry soils of intertropical regions. These are soils that must be drained during the rainy season and, if perennial crops are to be grown, irrigated during the dry season. Smith has previously proposed similar ustic subgroups for aquic great groups in several orders for soils in Guyana and Venezuela where dry seasons are very long, but rainy seasons very wet.

USTOLLIC To provide for this subgroup, the typic subgroup should be defined:

Do not have a subhorizon within 1.5 m of the surface that contains soft, powdery secondary lime.

Explanation The ustollic subgroup is provided in Soil Taxonomy for Eutrandepts. This merely continues the present subgroup, but because they would be restricted to Ustands, the subgroup name might better be "mollic" to prevent repetition of the formative element "ust."

VITRIC To provide for this subgroup, the typic subgroup should be defined:

Have 12% or more 15-bar water after air drying on the weighted average of all subhorizons between 25 cm and 1 m or a lithic or para-lithic contact shallower than 1 m.

Explanation Melanudands and Cryoborands include some soils that, in other suborders, would meet the definition of vitric great groups. The nature of the epipedon of Melanudands, and the temperature of Cryoborands are considered more important than the ashy nature of the soil. The haplic great groups, the 15-bar water content of the fresh samples may range from 30 to 100%, but the 15-bar water of air dried samples may be

APPENDIX A (Continued)

less than 12%, one of the limits of the ashy class. The vitric soils that are ashy are identified at the family level. The medial soils are not distinguished according to the dry 15-bar water contents at the great groups or family levels. This is considered the best available measure of the amount of amorphous clay present, and may range in haplic great groups for less than 10 to more than 30%.

Vitric subgroup should not have different definitions in different great groups, or the system becomes over complicated. Hence, only the 15-bar water content of dried samples is used in the definition, and the limit is one of the limits of the ashy class.

XERIC To provide for this subgroup, the typic subgroup should be defined:

Unless irrigated, are not dry in all parts of the moisture control section for as long as 45 consecutive days during the 6 months following the winter solstice, in 6 or more years out of 10.

Explanation The xeric subgroup definition is more or less parallel to that of the Xeric Albolls, but the period following the winter solstice has been extended to permit exhaustion of the ground water. These soils, like the ustic subgroups, require both drainage and irrigation for perennial crops or summer crops.

THAPTO-HISTIC To provide for this subgroup, the typic subgroup should be defined:

Do not have a buried Histosol with an upper boundary within 1 m of the surface.

Explanation This subgroup definition is parallel to others in Soil Taxonomy.

APPENDIX B

NEW PROPOSALS FOR DEFINITIONS OF CLASSES OF COMBINATIONS OF PARTICLE SIZE AND MINERALOGY*

The following classes are proposed:

Pumiceous

More than 60% of the whole soil is composed of pumice or pumice-like fragments coarser than 2 mm, with insufficent fine earth (or volcaniclastic materials) to fill interstices coarser than 1 mm in at least 10% of the volume of the soil; pumiceous fragments are two-thirds or more of the fragments coarser than 1 mm (by volume).

Cindery

Sixty percent or more of the whole soil (by weight) composed of volcanic ash, cinders, lapilli, and pumiceous fragments; one-third or more (by volume) is cinders and/or lapilli.

Ashy

More than 60% of the whole soil (by weight) volcanic ash, cinders, pumice, or other vitric volcaniclastics; less than 35% (by volume) is 2 mm in diameter or larger; less than 30% water retention at 15-bars on undried samples of fine earth, and less than 12% on air dried samples.

Ashy-pumiceous

Thirty five percent or more by volume is greater than 2 mm; pumice or pumice-like fragments larger than 2 mm are two thirds or more

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*Source: ICOMAND (1979) Circular No. 1.

APPENDIX B (Continued)

(by volume of the fraction greater than 2 mm; fine earth is otherwise ashy.

Ashy-skeletal

Thirty five percent or more by volume is greater than 2 mm; pumice and pumice-like fragments are less than two-thirds of the fraction greater than 2 mm; fine earth fraction is otherwise ashy.

Medial

Less than thirty five percent (by volume) is greater than 2 mm; water retention at 15-bars is 12% or more on previously dried samples; or water retention at 15-bars of undried samples is between 30 and 100%; the exchange complex is dominated by amorphous materials.

Medial-pumiceous

Thirty five percent or more (by volume) is greater than 2 mm; pumice or pumice-like fragments larger than 2 mm are two-thirds or more (by volume) of the fraction greater than 2 mm; fine earth is otherwise medial.

Medial-skeletal

Thirty five percent or more (by volume) is greater than 2 mm; pumice and pumice-like fragments are less than two-thirds (by volume) of the fraction greater than 2 mm; fine earth fraction otherwise medial.

Hydrous

Less than thirty five percent (by volume) is greater than 2 mm; water retention at 15-bars is 100% or more on undried samples of the fine earth; the exchange complex is dominated by amorphous materials.

APPENDIX B (Continued)

Hydrous-skeletal

Thirty five percent or more (by volume) is greater than 2 mm; pumice and pumice-like fragments are less than two-thirds of the fraction greater than 2 mm; fine earth fraction is otherwise hydrous. (Note: Hydrous-pumiceous is not presently known to occur but should be recognized if found).

APPENDIX C

FLOW-DIAGRAM KEYS OF SOIL ORDER ANDISOLS

KEY TO SUBORDERS OF ANDISOLS

Have artificial drainage, or aquic moisture regime, and have one or more of the following:
a. Histic epipedon
b. At a depth of < 50 cm or below the epipedon that has color value, moist, $\leqslant$ 3, dominant colors, moist on ped faces are:
   1. Chroma $\leqslant$ 2 if there is mottling.
   2. Chroma $\leqslant$ 1 if no mottling.
   3. Distinct, coarse or medium mottles due to segregation of Fe within or below 18 cm of the surface.

AQUAND — YES — NO

Frigid or cryic temperature regime

BORAND — YES — NO

Xeric moisture regime

XERAND — YES — NO

Ustic moisture regime, or duripan, or both

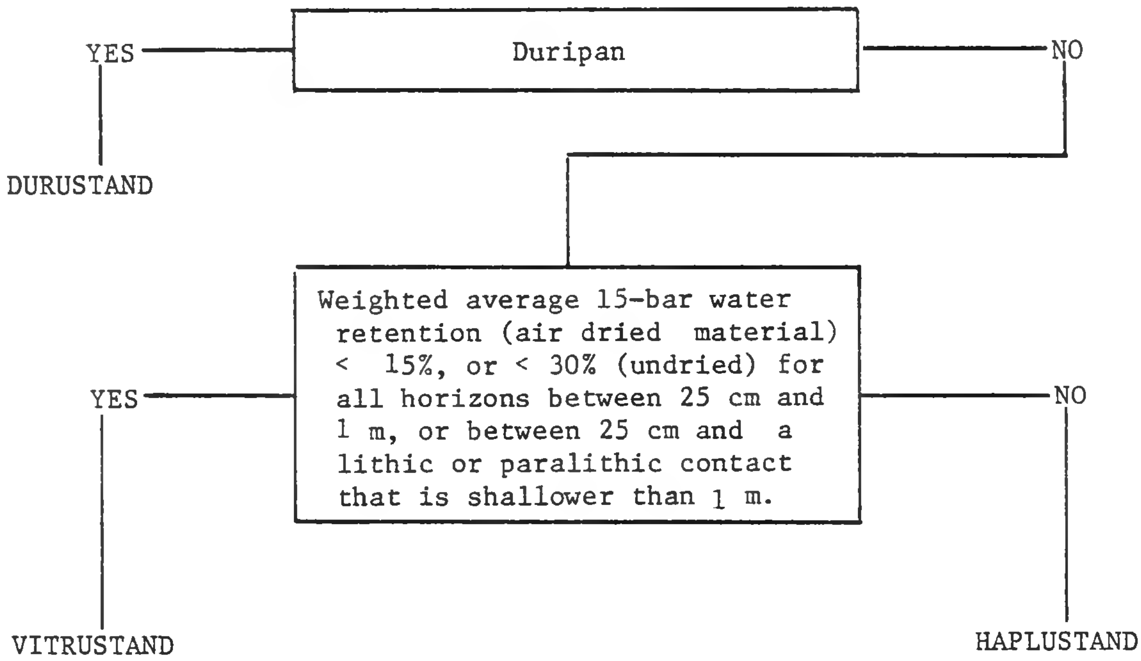
USTAND — YES — NO

Isomesic or a warmer iso-temperature regime or hyperthermic

TROPAND — YES — NO* — UDAND

* Have udic or perudic moisture regime.

KEY TO GREAT GROUPS OF USTANDS



KEY TO GREAT GROUPS OF TROPANDS

Placic horizon within 1 m of the soil surface in half or more of each pedon.

YES — PLACOTROPAND

NO

Have 15-bar water retention of undried samples of 100% or more and a molar ratio of $SiO_2/Al_2O_3 < 0.85$, both on the weighted average of all horizons between 25 cm and 1 m or a lithic or paralithic contact shallower than 1 m.

YES — HYDROTROPAND

NO

Weighted average 15-bar water retention (air dried) < 15% or < 30% (undried) for all horizons between 25 cm and 1 m or between 25 cm and a lithic or paralithic contact that is shallower than 1 m.

YES — VITRITROPAND

NO — HAPLOTROPAND

KEY TO SUBGROUPS OF VITRUSTANDS

Lithic contact within 50 cm of surface.

YES → LITHIC

NO ↓

Organic carbon ≤ 5% throughout upper 25 cm of soil or have a subsurface horizon with upper boundary within 30 cm of the surface that is ≤ 5%.

YES → ENTIC

NO ↓

Have a mollic epipedon, or have less than 70% fine to coarse sand (0.1 to 2mm), or more than 35%, in volume, greater than 2 mm in some subhorizon within 1 m of the surface.

YES → MOLLIC

NO → TYPIC

KEY TO SUBGROUPS OF HAPLUSTANDS

Lithic contact within 50 cm of the surface.
YES — LITHIC
NO —

Have distinct or prominent medium or coarse mottles due to segretation of Fe, or
Have mottles with chroma $\leqslant 2$, within 1 m of the soil surface if the mottled horizon is saturated with water at some season of the year, or
The soil is artificially drained.
YES — AQUIC
NO —

Organic carbon > 5% throughout the upper 25 cm of soil, or
A layer with the upper boundary < 30 cm from surface that has organic carbon > 5% throughout its upper 25 cm.
YES —
NO — ENTIC

Weighted average 15-bar water retention (air dry) between 25 cm and 1 m is <12% and 1 m, or between 25 cm and a lithic or paralithic contact that is shallower than 1 m.
YES — VITRIC
NO —

Subhorizon with 1.5 m of the surface that contains soft, powdery secondary lime.
YES —
NO —

Does not have mollic epipedon.
YES — CALCIC
NO — TYPIC

KEY TO SUBGROUPS OF HYDROTROPANDS

YES	Test	NO
LITHIC	Lithic contact within 50 cm of surface.	(next test)
RUPTIC-PLACIC	Intermittent placic horizon within 1 m of the surface in more than 1/5 of the area of each pedon.	(next test)
ACRIC	Positive ΔpH in any horizon between 25 cm and 1 m, or to a lithic or paralithic contact shallower than 1 m.	TYPIC

KEY TO SUBGROUPS OF HAPLOTROPANDS

Lithic contact within 50 cm of surface.

YES — LITHIC

NO

Intermittent placic horizon within 1 m of the surface in more than 1/5 of each pedon.

YES — RUPTIC-PLACIC

NO

Distinct medium or coarse mottles due to segregation of Fe, or
Mottles with chroma <2 within 1 m of the soil surface is mottled horizon is saturated with water at some season of the year, or
The soil is artificially drained.

YES — AQUIC

NO

Organic carbon >5% throughout the upper 25 cm of soil, or
A layer with upper boundary <30 cm from surface that has organic carbon >5%.

YES

NO — ENTIC

Have a positive ΔpH in any horizon between 25 cm and 1 m or to a lithic or paralithic contact shallower than 1 m.

YES — ACRIC

NO

Have a weighted average ratio of 15-bar water retention between 25 cm and 1 m to percent organic carbon within 18 cm >10.

YES — HYDRIC

NO

Weighted average 15-bar water retention (air dry) <12% for all subhorizons between 25 cm and 1 m, or a lithic or paralithic contact shallower than 1 m.

YES — VITRIC

NO — TYPIC

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